Henry. McElfresh

~~Frederick~~

February 22d 1848

PRINCIPLES

OF

GEOLOGY.

VOL. II.

PRINCIPLES

OF

GEOLOGY:

OR, THE

MODERN CHANGES

OF THE EARTH AND ITS INHABITANTS,

CONSIDERED AS ILLUSTRATIVE OF GEOLOGY.

BY

CHARLES LYELL, ESQ., F.R.S.

"Verè scire est per causas scire." — BACON.

IN THREE VOLUMES.

VOL. II.

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The remaining class of deltas are those in which rivers, on entering the sea, are exposed to the influence of the tides. In this case it frequently happens that an estuary is produced, or negative delta, as Rennell termed it, where, instead of any encroachment of the land upon the sea, the ocean enters the river's mouth, and penetrates into the land beyond the general coast-line. Where this happens, the tides and currents are the predominating agents in the distribution of transported sediment. The phenomena, therefore, of such estuaries, will be treated of when the

movements of the ocean come under consideration. But whenever the volume of fresh water is so great as to counteract and almost neutralize the force of tides and currents, and in all cases where these agents have not sufficient power to remove to a distance the whole of the sediment periodically brought down by rivers, oceanic deltas are produced. Of these, I shall now select a few illustrative examples.

Delta of the Ganges. — The Ganges and the Burrampooter descend, from the highest mountains in the world, into a gulf which runs 225 miles into the continent. The Burrampooter is somewhat the larger river of the two; but it takes the name of the Megna, in lat. 24° N., when joined by a smaller stream so called, and afterwards loses this second name on its union with the principal arm of the Ganges, at the distance of about forty miles from the sea. The area of the delta of the Ganges (without including that of the Burrampooter, which has now become conterminous) is considerably more than double that of the Nile; and its head commences at a distance of 220 miles in a direct line from the sea. Its base is two hundred miles in length, including the space occupied by the two great arms of the Ganges which bound it on either side. That part of the delta which borders on the sea is composed of a labyrinth of rivers and creeks, all filled with salt water, except those immediately communicating with the principal arm of the Ganges. This tract alone, known by the name of the Woods, or Sunderbunds, a wilderness infested by tigers and alligators, is, according to Rennell, equal in extent to the whole principality of Wales.*

* Account of the Ganges and Burrampooter Rivers, by Major Rennell, Phil. Trans. 1781.

On the sea-coast there are eight great openings, each of which has evidently, at some ancient period, served in its turn as the principal channel of discharge. Although the flux and reflux of the tide extend even to the head of the delta when the river is low; yet, when it is periodically swollen by tropical rains, the velocity of the stream counteracts the tidal current, so that, except very near the sea, the ebb and flow become insensible. During the flood season, therefore, the Ganges almost assumes the character of a river entering a lake or inland sea; the movements of the ocean being then subordinate to the force of the river, and only slightly disturbing its operations. The great gain of the delta in height and area takes place during the inundations; and, during other seasons of the year, the ocean makes reprisals, scouring out the channels, and sometimes devouring rich alluvial plains.

So great is the quantity of mud and sand poured by the Ganges into the gulf in the flood season, that the sea only recovers its transparency at the distance of sixty miles from the coast. The general slope, therefore, of the new strata must be extremely gradual. By the charts recently published, it appears that there is a gradual deepening from four to about sixty fathoms, as we proceed from the base of the delta to the distance of about one hundred miles into the Bay of Bengal. At some few points seventy, or even one hundred, fathoms are obtained at that distance.

One remarkable exception, however, occurs to the regularity of the shape of the bottom; for, opposite the middle of the delta, at the distance of thirty or forty miles from the coast, is a nearly circular space called the "swatch of no ground," about fifteen miles in diameter, where soundings of 100, and even 130,

fathoms fail to reach the bottom. This phenomenon is the more extraordinary, since the depression occurs within five miles of the line of shoals; and not only do the waters charged with Gangetic sediment pass over it continually; but, during the monsoons, the sea, loaded with mud and sand, is beaten back in that direction towards the delta. As the mud is known to extend for eighty miles farther into the gulf, an enormous thickness of matter must have been deposited in "the swatch." We may conclude, therefore, either that the original depth of this part of the Bay of Bengal was excessive, or that subsidences have occurred in modern times. The latter conjecture is the less improbable, as the contiguous region of Chittagong has been convulsed in the historical era by earthquakes, and "the swatch" lies not far from that volcanic band which connects Sumatra and Barren island with Assam.*

Opposite the mouth of the Hoogly river, and immediately south of Sangor Island, four miles from the nearest land of the delta, a new islet was formed about twenty years ago, called Edmonstone Island, on the centre of which a beacon was erected as a landmark in 1817. In 1818 the island had become two miles long and half a mile broad, and was covered with vegetation and shrubs. Some houses were then built upon it, and in 1820 it was used as a pilot station. The severe gale of 1823 divided it into two parts, and so reduced its size as to leave the beacon standing out in the sea, where after remaining seven years it was washed away. The islet in 1836 had been converted by successive storms into a sand-bank, half a mile long, on which a sea-mark was placed.

* See M'Clelland's Report on Geol. of India, and map of Volcanic Bands, plate vi. Book ii. chap. 10.

Although there is evidence of gain at some points, the general progress of the coast is very slow; for the tides, which rise from thirteen to sixteen feet, are actively employed in removing the alluvial matter, and diffusing it over a wide area. The new strata consist entirely of sand and fine mud: such, at least, are the only materials which are exposed to view in regular beds on the banks of the numerous creeks. No substance so coarse as gravel occurs in any part of the delta, nor nearer the sea than 400 miles.

Islands formed and destroyed.— Major R. H. Colebrooke, in his account of the course of the Ganges, relates examples of the rapid filling up of some of its branches, and the excavation of new channels, where the number of square miles of soil removed in a short time (the column of earth being 114 feet high) was truly astonishing. Forty square miles, or 25,600 acres, are mentioned as having been carried away, in one place in the course of a few years.* The immense transportation of earthy matter by the Ganges and Megna is proved by the great magnitude of the islands formed in their channels during a period far short of that of a man's life. Some of these, many miles in extent, have originated in large sand-banks thrown up round the points at the angular turning of the river, and afterwards insulated by breaches of the stream. Others, formed in the main channel, are caused by some obstruction at the bottom. A large tree, or a sunken boat, is sometimes sufficient to check the current, and cause a deposit of sand, which accumulates till it usurps a considerable portion of the channel. The river then undermines its banks on each side, to supply the deficiency in its bed, and the island is after-

* Trans. of the Asiatic Society, vol. vii. p. 14.

wards raised by fresh deposits during every flood. In the great gulf below Luckipour, formed by the united waters of the Ganges and Megna, some of the islands, says Rennell, rival in size and fertility the Isle of Wight. While the river is forming new islands in one part, it is sweeping away old ones in others. Those newly formed are soon overrun with reeds, long grass, the Tamarix Indica, and other shrubs, forming impenetrable thickets, where tigers, buffaloes, deer, and other wild animals, take shelter. It is easy, therefore, to perceive, that both animal and vegetable remains must continually be precipitated into the flood, and sometimes become imbedded in the sediment which subsides in the delta.

Two species of crocodiles, of distinct genera, abound in the Ganges and its tributary and contiguous waters; and Mr. H. T. Colebrooke informs me, that he has seen both kinds in places far inland, many hundred miles from the sea. The Gangetic crocodile, or Gavial, (in correct orthography, Garial,) is confined to the fresh water, but the common crocodile frequents both fresh and salt; being much larger and fiercer in salt and brackish water. These animals swarm in the brackish water along the line of sand-banks where the advance of the delta is most rapid. Hundreds of them are seen together in the creeks of the delta, or basking in the sun on the shoals without. They will attack men and cattle, destroying the natives when bathing, and tame and wild animals which come to drink. "I have not unfrequently," says Mr. Colebrooke, "been witness to the horrid spectacle of a floating corpse seized by a crocodile with such avidity, that he half emerged above the water with his prey in his mouth." The geologist will not fail to observe how peculiarly the habits and distribution of these saurians

expose them to become imbedded in the horizontal strata of fine mud, which are annually deposited over many hundred square miles in the Bay of Bengal. The inhabitants of the land, which happen to be drowned or thrown into the water, are usually devoured by these voracious reptiles; but we may suppose the remains of the saurians themselves to be continually entombed in the new formations.

Inundations.—It sometimes happens, at the season when the periodical flood is at its height, that a strong gale of wind, conspiring with a high spring-tide, checks the descending current of the river, and gives rise to most destructive inundations. From this cause, in the year 1763, the waters at Luckipour rose six feet above their ordinary level, and the inhabitants of a considerable district, with their houses and cattle, were totally swept away.

The population of all oceanic deltas are particularly exposed to suffer by such catastrophes, recurring at considerable intervals of time; and we may safely assume that such tragical events have happened again and again since the Gangetic delta was inhabited by man. If human experience and forethought cannot always guard against these calamities, still less can the inferior animals avoid them; and the monuments of such disastrous inundations must be looked for in great abundance in strata of all ages, if the surface of our planet has always been governed by the same laws. When we reflect on the general order and tranquillity that reigns in the rich and populous delta of Bengal, notwithstanding the havoc occasionally committed by the depredations of the ocean, we perceive how unnecessary it is to attribute the imbedding of successive races of animals in older strata to extraordinary energy

in the causes of decay and reproduction in the infancy of our planet, or to those general catastrophes and sudden revolutions resorted to by some theorists.

Delta of the Mississippi. — As the delta of the Ganges may be considered a type of those formed on the borders of the ocean, it will be unnecessary to accumulate examples of others on a no less magnificent scale, as, for example, at the mouths of the Orinoco and Amazon. To these, however, I shall revert by and by, when treating of the agency of currents. The tides in the Mexican Gulf are so feeble that the delta of the Mississippi has somewhat of an intermediate character between an oceanic and mediterranean delta. A long narrow tongue of land is protruded, consisting simply of the banks of the river, wearing precisely the same appearance as in the inland plains during the periodical inundations, when nothing appears above water but the higher part of the sloping glacis before described.* This tongue of land has advanced many leagues since New Orleans was built. Great submarine deposits are also in progress, stretching far and wide over the bottom of the sea, which has become extremely shallow, not exceeding ten fathoms in depth. Opposite the mouth of the Mississippi large rafts of drift trees, brought down every spring, are matted together into a net-work, many yards in thickness, and stretching over hundreds of square leagues.† They afterwards become covered over with a fine mud, on which other layers of trees are deposited the year following, until numerous alternations of earthy and vegetable matter are accumulated.

* Chapter ii.

† Captain Hall's Travels in North America, vol. iii. p. 338.— See also above, chap. ii.

An observation of Darby, in regard to the strata composing part of this delta, deserves attention. In the steep banks of the Atchafalaya, an arm of the Mississippi before alluded to in our description of "the raft," the following section is observable at low water:—first, an upper stratum, consisting invariably of blueish clay, common to the banks of the Mississippi; below this a stratum of red ochreous earth, peculiar to Red River, under which the blue clay of the Mississippi again appears; and this arrangement is constant, proving, as that geographer remarks, that the waters of the Mississippi and the Red River occupied alternately, at some former periods, considerable tracts below their present point of union.* Such alternations are probably common in submarine spaces situated between two converging deltas; for, before the two rivers unite, there must almost always be a certain period when an intermediate tract will by turns be occupied and abandoned by the waters of each stream; since it can rarely happen that the season of highest flood will precisely correspond in each. In the case of the Red River and Mississippi, which carry off the waters from countries placed under widely distant latitudes, an exact coincidence in the time of greatest inundation is very improbable.

CONCLUDING REMARKS ON DELTAS.

Quantity of sediment in river water.—Very few satisfactory experiments have as yet been made, to enable us to determine, with any degree of accuracy, the mean quantity of earthy matter discharged annually

* Darby's Louisiana, p. 103.

into the sea by some one of the principal rivers of the earth. Hartsoeker computed the Rhine to contain in suspension, when most flooded, one part in a hundred of mud in volume;* but it appears from two sets of experiments, recently made by Mr. Leonard Horner, at Bonn, that $\frac{1}{10000}$th would have been a nearer approximation to the truth.† Mr. Barrow, in his journal, cited by Sir George Staunton, inferred from several observations, that the water of the Yellow River in China contained earthy matter in the proportion of one part to two hundred, and he calculated that it brought down in a single hour two million cubic feet of earth, or forty-eight million daily; so that, if the Yellow Sea be taken to be 120 feet deep, it would require seventy days for the river to convert an English square mile into firm land, and 24,000 years to turn the whole sea into terra firma, assuming it to be 125,000 square miles in area.‡ Manfredi, the celebrated Italian hydrographer, conceived the average proportion of sediment in all the running water on the globe, which reached the sea, to be $\frac{1}{175}$, and he imagined that it would require a thousand years for the sediment carried down to raise the general level of the sea about one foot. Some writers, on the contrary, as De Maillet, have declared the most turbid waters to contain far less sediment. One of the most extraordinary statements is that of Major Rennell, in his excellent paper, before referred to, on the delta of the Ganges. "A glass of water," he says, "taken out of this river when at its height, yields about one part in four of

* Comment. Bonon., vol. ii. part i. p. 237.

† Edin. New Phil. Journ., Jan. 1835.

‡ Staunton's Embassy to China, Lond. 1797, 4to. vol. ii. p. 410.

mud. No wonder, then," he adds, "that the subsiding waters should quickly form a stratum of earth, or that the delta should encroach on the sea!" *

There must certainly be some mistake, perhaps a misprint, in the statement in the Phil. Trans.; and some have conjectured that the learned hydrographer meant one part in four hundred of mud. In the earlier editions of this work, I expressed my regret that so much inconsistency and contradiction should be found in the statements and speculations relative to this interesting subject; and I endeavoured to point out the high geological importance of reducing to arithmetical computation the aggregate amount of solid matter transported by certain large rivers to the sea. The deficiency of data has now been, in some degree, removed by the labours of the Rev. Mr. Everest, who has instituted a series of observations "On the earthy matter brought down by the Ganges" at Ghazipúr, in Bengal.†

The first step to be made in all such calculations is to ascertain the average volume of water passing annually down the channel of a river. This might easily be accomplished if the breadth, depth, and velocity of a stream were constant and uniform throughout the year; but as all these conditions are liable to vary according to the seasons, the problem becomes extremely complex. In the Ganges, as in other rivers in hot climates, there are periodical inundations, during which by far the greatest part of the annual discharge takes place; and the most important point, therefore,

* Phil. Trans. 1781.

† Journ. of Asiatic Soc., No. 6. p. 238. June, 1832. See also Mr. Prinsep, Gleanings in Science, vol. iii. p. 185.

to determine, is the mean breadth, depth, and velocity of the stream during this period.

Mr. Everest found that, in 1831, the number of cubic feet of water discharged by the Ganges per second was, during the

Rains, (4 months)	- -	494,208
Winter, (5 months)	- -	71,200
Hot weather, (3 months)	-	36,330

so that we may state in round numbers, that 500,000 cubic feet per second flow down during the four months of the flood season, from June to September, and less than 60,000 per second during the remaining eight months.

Having obtained the volume of water, we have next to inquire what is the proportion of solid matter contained in it; and for this purpose, a definite quantity, as, for example, a quart, is taken from the river on different days, sometimes from the middle of the current, and sometimes nearer the banks. This water is then evaporated, the solid residuum weighed, and the mean quantity of sediment thus ascertained, throughout the rainy season. The same observations must then be repeated for the other portions of the year.

In computing the quantity of water, Mr. Everest made no allowance for the decreased velocity of the stream near the bottom, presuming that it is compensated by the increased weight of matter held in suspension there. Probably the amount of sediment is by no means exaggerated by this circumstance; but rather under-rated, as the heavier grains of sand, which can never rise into the higher parts of the stream, are drifted along the bottom.

Now the average quantity of solid matter suspended in the water during the rains was, by weight $\frac{1}{428}$th part; but, as the water is about one half the specific gravity of the dried mud, the solid matter discharged is $\frac{1}{856}$th part in bulk, or 577 cubic feet per second. This gives a total of 6,082,041,600 cubic feet for the discharge in the 122 days of the rain. The proportion of sediment in the waters at other seasons was comparatively insignificant, the total amount during the five winter months being only 247,881,600 cubic feet, and during the three months of hot weather 38,154,240 cubic feet. The total annual discharge, then, would be 6,368,077,440 cubic feet.

In order to give some idea of the magnitude of this result, we will assume that the specific gravity of the dried mud is only one half that of granite (it would, however, be more): in that case, the earthy matter discharged in a year would equal 3,184,038,720 cubic feet of granite. Now about 12½ cubic feet of granite weigh one ton; and it is computed that the great Pyramid of Egypt, if it were a solid mass of granite, would weigh about 6,000,000 tons. The mass of matter, therefore, carried down annually, would, according to this estimate, more than equal in weight and bulk forty-two of the great pyramids of Egypt, and that borne down in the four months of the rains would equal forty pyramids. But if, without any conjecture as to what may have been the specific gravity of the mud, we attend merely to the weight of solid matter actually proved by Mr. Everest to have been contained in the water, we find that the number of tons weight which passed down in the 122 days of the rainy season was 339,413,760, which would give the weight of fifty-six pyramids and a half; and in the

whole year 355,361,464 tons, or nearly the weight of sixty pyramids.

The base of the great Pyramid of Egypt covers eleven acres, and its perpendicular height is about five hundred feet. It is scarcely possible to present any picture to the mind which will convey an adequate conception of the mighty scale of this operation, so tranquilly and almost insensibly carried on by the Ganges, as it glides through its alluvial plain. It may, however, be stated, that if a fleet of more than eighty Indiamen, each freighted with about 1400 tons weight of mud, were to sail down the river every hour of every day and night for four months continuously, they would only transport from the higher country to the sea a mass of solid matter equal to that borne down by the Ganges in the four months of the flood season. Or the exertions of a fleet of about 2000 such ships going down daily with the same burden, and discharging it into the gulf, would be no more than equivalent to the operations of the great river. Yet, in addition to this, it is probable that the Burrumpooter conveys annually as much solid matter to the sea as the Ganges.

The most voluminous current of lava which has flowed from Etna within historical times was that of 1669. Ferrara, after correcting Borrelli's estimate, calculated the quantity of cubic yards of lava in this current at 140,000,000. Now, this would not equal in bulk one fifth of the sedimentary matter which is carried down in a single year by the Ganges, according to the estimate above explained; so that it would require five grand eruptions of Etna to transfer a mass of lava from the subterranean regions to the surface,

equal in volume to the mud carried down to the sea in one year by a single river in Bengal.

Grouping of Strata in Deltas.— The changes which have taken place in deltas, ever since the times of history, may suggest many important considerations in regard to the manner in which subaqueous sediment is distributed. Notwithstanding frequent exceptions, arising from the interference of a variety of causes, there are some general laws of arrangement which must evidently hold good in almost all the lakes and seas now filling up. If a lake, for example, be encircled on two sides by lofty mountains, receiving from them many rivers and torrents of different sizes, and if it be bounded on the other sides, where the surplus waters issue, by a comparatively low country, it is not difficult to define some of the leading geological features which must characterize the lacustrine formation, when this basin shall have been gradually converted into dry land by the influx of sediment. The strata would be divisible into two principal groups: the *older* comprising those deposits which originated on the side adjoining the mountains, where numerous deltas first began to form; and the *newer* group consisting of beds deposited in the more central parts of the basin, and towards the side farthest from the mountains. The following characters would form the principal marks of distinction between the strata in each series. The more ancient system would be composed, for the most part, of coarser materials containing many beds of pebbles and sand, often of great thickness, and sometimes dipping at a considerable angle. These, with associated beds of finer ingredients, would, if traced round the borders of the basin, be seen to vary greatly in colour and mineral com-

position, and would also be very irregular in thickness. The beds, on the contrary, in the newer group, would consist of finer particles, and would be horizontal, or very slightly inclined. Their colour and mineral composition would be very homogeneous throughout large areas, and would differ from almost all the separate beds in the older series.

The following causes would produce the diversity here alluded to between the two great members of such lacustrine formations: — When the rivers and torrents first reach the edge of the lake, the detritus washed down by them from the adjoining heights sinks at once into deep water, all the heavier pebbles and sand subsiding near the shore. The finer mud is carried somewhat farther out, but not to the distance of many miles, for the greater part may be seen, as, for example, where the Rhone enters the Lake of Geneva, to fall down in clouds to the bottom not far from the river's mouth. Thus alluvial tracts are soon formed at the mouths of every torrent and river, and many of these in the course of ages become of considerable extent. Pebbles and sand are then transported farther from the mountains; but in their passage they decrease in size by attrition, and are in part converted into mud and sand. At length some of the numerous deltas which are all directed towards a common centre approach near to each other — those of adjoining torrents become united, and each is merged, in its turn, in the delta of the largest river, which advances most rapidly into the lake, and renders all the minor streams, one after the other, its tributaries. The various mineral ingredients of all are thus blended together into one homogeneous mixture, and the sediment is poured out from a common channel into the lake.

As the average size of the transported particles decreases, while the force and volume of the main river augments, the newer deposits are diffused continually over a wider area, and are consequently more horizontal than the older. When at first there were many independent deltas near the borders of the basin, their separate deposits differed entirely from each other; one may have been charged, like the Arve where it joins the Rhone, with white sand, and sediment derived from granite — another may have been black, like many streams in the Tyrol, flowing from the waste of decomposing rocks of dark slate — a third may have been coloured by ochreous sediment, like the Red River in Louisiana — a fourth, like the Elsa in Tuscany, may have held much carbonate of lime in solution. At first they would each form distinct deposits of sand, gravel, limestone, marl, or other materials; but after their junction new chemical combinations and a distinct colour would be the result, and the particles, having been conveyed ten, twenty, or a greater number of miles over alluvial plains, would become finer.

In deltas where the causes are more complicated, and where tides and currents partially interfere, the above description would only be applicable, with certain modifications; but if a series of earthquakes accompany the growth of a delta, and change the levels of the land from time to time, as in the region where the Indus now enters the sea, and others hereafter to be mentioned, the phenomena will then depart still more widely from the ordinary type.

Convergence of Deltas. — If we possessed an accurate series of maps of the Adriatic for many thousand years, our retrospect would, without doubt, carry us

gradually back to the time when the number of rivers descending from the mountains into that gulf by independent deltas was far greater in number. The deltas of the Po and the Adige, for instance, would separate themselves within the *recent* era, as, in all probability, would those of the Isonzo and the Torre. If, on the other hand, we speculate on future changes, we may anticipate the period when the number of deltas will greatly diminish; for the Po cannot continue to encroach at the rate of a mile in a hundred years, and other rivers to gain as much in six or seven centuries upon the shallow gulf, without new junctions occurring from time to time, so that Eridanus, "the king of rivers," will continually boast a greater number of tributaries. The Ganges and the Burrampooter have probably become confluent within the historical era; and the date of the junction of the Red River and the Mississippi would, in all likelihood, have been known if America had not been so recently discovered. The union of the Tigris and the Euphrates must undoubtedly have been one of the modern geographical changes on our earth, and similar remarks might be extended to many other regions.

When the deltas of rivers, having many mouths, converge, a partial union at first takes place by the confluence of some one or more of their arms; but it is not until the main trunks are connected above the head of the common delta, that a complete intermixture of their joint waters and sediment takes place. The union, therefore, of the Po and Adige, and of the Ganges and Burrampooter, is still incomplete. If we reflect on the geographical extent of surface drained by rivers such as now enter the Bay of Bengal, and then consider how complete the blending together of

the greater part of their transported matter has already become, and throughout how vast a delta it is spread by numerous arms, we no longer feel so much surprise at the area occupied by some ancient formations of homogeneous mineral composition. But our surprise will be still further lessened when we afterwards inquire into the action of tides and currents, in disseminating sediment.*

Formation of Conglomerates. — Along the base of the Maritime Alps, between Toulon and Genoa, the rivers, with few exceptions, are now forming strata of conglomerate and sand. Their channels are often several miles in breadth, some of them being dry, and the rest easily forded for nearly eight months in the year, whereas during the melting of the snow they are swollen, and a great transportation of mud and pebbles takes place. In order to keep open the main road from France to Italy, now carried along the sea-coast, it is necessary to remove annually great masses of shingle brought down during the flood-season. A portion of the pebbles are seen in some localities, as near Nice, to form beds of shingle along the shore, but the greater part are swept into a deep sea. The small progress made by the deltas of minor rivers on this coast need not surprise us, when we recollect that there is sometimes a depth of two thousand feet at a few hundred yards from the beach, as near Nice. Similar observations might be made respecting a large proportion of the rivers in Sicily, and, among others, respecting that which, immediately north of the port of Messina, hurries annually vast masses of granitic pebbles into the sea.

* See Chap. ix.

Causes of Stratification in Deltas. — The stratified arrangement which is observed to prevail so generally in aqueous deposits is most frequently due to variations in the velocity of running water, which cannot sweep along particles of more than a certain size and weight when moving at a given rate. Hence, as the force of the stream augments or decreases, the materials thrown down in successive layers at particular places are rudely sorted, according to their dimensions, forms, and specific gravity. Where this cause has not operated, as where sand, mud, and fragments of rock are conveyed by a glacier, a confused heap of rubbish devoid of all stratification is produced.

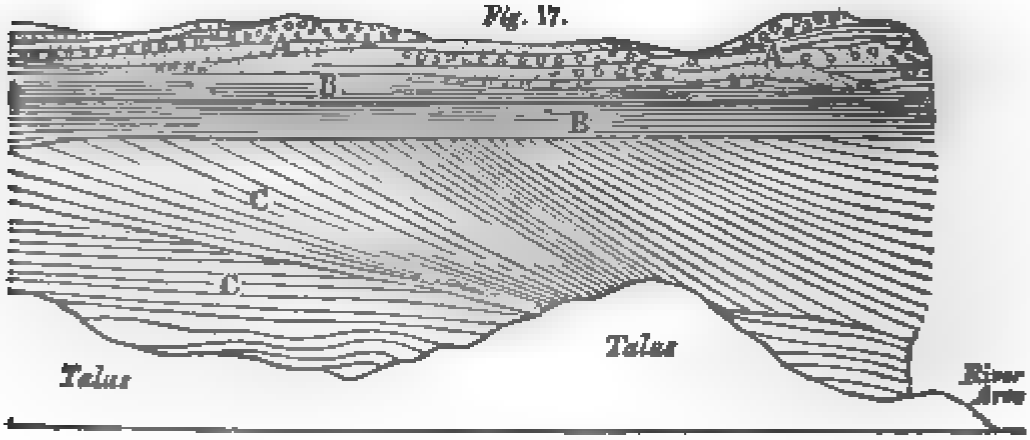
Natural divisions are also occasioned in deltas by the interval of time which separates annually the deposition of matter during the periodical rains, or melting of the snow upon the mountains. The deposit of each year may acquire some degree of consistency before that of the succeeding year is superimposed. A variety of circumstances also give rise annually, or sometimes from day to day, to slight variations in colour, fineness of the particles, and other characters, by which alternations of strata distinct in texture, and mineral ingredients must be produced. Thus, for example, at one period of the year, drift wood may be carried down, and at another mud, as was before stated to be the case in the delta of the Mississippi; or at one time, when the volume and velocity of the stream are greatest, pebbles and sand may be spread over a certain area, over which, when the waters are low, fine matter or chemical precipitates are formed. During inundations, the turbid current of fresh water often repels the sea for many miles; but when the river is low salt water again occupies the same space. When two

deltas are converging, the intermediate space is often, for reasons before explained, alternately the receptacle of different sediments derived from the converging streams. (See p. 9.) The one is, perhaps, charged with calcareous, the other with argillaceous matter; or one sweeps down sand and pebbles, the other impalpable mud. These differences may be repeated, with considerable regularity, until a thickness of hundreds of feet of alternating beds is accumulated. The multiplication, also, of shells and corals in particular spots, and for limited periods, gives rise occasionally to lines of separation, and divides a mass which might otherwise be homogeneous in distinct strata.

An examination of the shell marl now forming in the Scotch lakes, or the sediment termed "warp," which subsides from the muddy water of the Humber, and other rivers, shews that recent deposits are often composed of a great number of extremely thin layers, either even or slightly undulating, and preserving a general parallelism to the planes of stratification. Sometimes, however, the laminæ in modern strata are disposed diagonally at a considerable angle, which appears to take place where there are conflicting movements in the waters. In January, 1829, I visited, in company with Professor L. A. Necker, of Geneva, the confluence of the Rhone and Arve, when those rivers were very low, and were cutting channels through the vast heaps of débris thrown down from the waters of the Arve, in the preceding spring. One of the sandbanks which had formed, in the spring of 1828, where the opposing currents of the two rivers neutralized each other, and caused a retardation in the motion, had been undermined; and the following is an exact representation of the arrangement of laminæ exposed

in a vertical section. The length of the portion here seen is about twelve feet, and the height five. The strata A A consist of irregular alternations of pebbles and sand in undulating beds: below these are seams of very fine sand B B, some as thin as paper, others about a quarter of an inch thick. The strata C C are composed of layers of fine greenish-grey sand, as thin as paper. Some of the inclined beds will be seen to

Fig. 17.



Section of a sand bank in the bed of the Arve at its confluence with the Rhone, showing the stratification of deposits where currents meet.

be thicker at their upper, others at their lower extremity, the inclination of some being very considerable. These layers must have accumulated one on the other by lateral apposition, probably when one of the rivers was very gradually increasing or diminishing in velocity, so that the point of greatest retardation caused by their conflicting currents shifted slowly, allowing the sediment to be thrown down in successive layers on a sloping bank. The same phenomenon is exhibited in older strata of all ages.*

Constant interchange of land and sea. — I may here conclude my remarks on deltas, observing that, im-

* See Elements of Geology by the Author.

perfect as is our information of the changes which they have undergone within the last three thousand years, they are sufficient to show how constant an interchange of sea and land is taking place on the face of our globe. In the Mediterranean alone, many flourishing inland towns, and a still greater number of ports, now stand where the sea rolled its waves since the era of the early civilization of Europe. If we could compare with equal accuracy the ancient and actual state of all the islands and continents, we should probably discover that millions of our race are now supported by lands situated where deep seas prevailed in earlier ages. In many districts not yet occupied by man, land animals and forests now abound where ships once sailed, and on the other hand, we shall find, on inquiry, that inroads of the ocean have been no less considerable. When to these revolutions, produced by aqueous causes, we add analogous changes wrought by igneous agency, we shall, perhaps, acknowledge the justice of the conclusion of Aristotle, who declared that the whole land and sea on our globe periodically changed places.*

* See Vol. i. p. 22.

CHAPTER VII.

DESTROYING AND TRANSPORTING EFFECTS OF TIDES AND CURRENTS.

Differences in the rise of the tides — Rennell's Account of the Lagullas and Gulf currents — Velocity of currents — Causes of currents — Action of the sea on the British coast — Shetland Islands — Large blocks removed — Effects of lightning — Isles reduced to clusters of rocks — Orkney Isles — Waste of East coast of Scotland — and East coast of England — Waste of the cliffs of Holderness, Norfolk, and Suffolk — Silting up of estuaries — Origin of submarine forests — Yarmouth estuary — Suffolk coast — Dunwich — Essex coast — Estuary of the Thames — Goodwin Sands — Coast of Kent — Formation of Straits of Dover — South coast of England — Sussex — Hants — Dorset — Portland — Origin of the Chesil Bank — Cornwall — Coast of Brittany.

Although the movements of great bodies of water, termed tides and currents, are in general due to very distinct causes, their effects cannot be studied separately; for they produce, by their joint action, those changes which are objects of geological interest. These forces may be viewed in the same manner as we before considered rivers, first, as employed in destroying portions of the solid crust of the earth, and removing them to other places; secondly, as reproductive of new strata.

Tides. — It would be superfluous at the present day to offer any remarks on the cause of the tides. They are not perceptible in lakes, or in most inland seas;

in the Mediterranean even, deep and extensive as is that sea, they are scarcely sensible to ordinary observation, their effects being quite subordinate to those of the winds and currents. In some places, however, as in the Straits of Messina, there is an ebb and flow to the amount of two feet and upwards; at Naples and at the Euripus, of twelve or thirteen inches; and at Venice, according to Rennell, of five feet.* In the Syrtes, also, of the ancients, two wide shallow gulfs, which penetrate very far within the northern coast of Africa, between Carthage and Cyrene, the rise is said to exceed five feet.†

In islands remote from any continent, the ebb and flow of the ocean is very slight, as at St. Helena, for example, where it is rarely above three feet.‡ In any given line of coast, the tides are greatest in narrow channels, bays, and estuaries, and least in the intervening tracts where the land is prominent. Thus, at the entrance of the estuary of the Thames and Medway, the rise of the spring tides is eighteen feet; but when we follow our eastern coast from thence northward, towards Lowestoff and Yarmouth, we find a gradual diminution, until, at the places last mentioned, the highest rise is only seven or eight feet. From this point there begins again to be an increase, so that at Cromer, where the coast again retires towards the west, the rise is sixteen feet; and towards the extremity of the gulf called "the Wash," as at Lynn and in Boston deeps, it is from twenty-two to twenty-four feet, and in some extraordinary cases twenty-six feet. From

* Geog. of Herod. vol. ii. p. 331. † Ibid. p. 328.

‡ Romme, Vents et Courans, vol. ii. p. 2. Rev. F. Fallows, Quart. Journ. of Science, March, 1829.

thence again there is a decrease towards the north, the elevation at the Spurn Point being from nineteen to twenty feet, and at Flamborough Head and the Yorkshire coast from fourteen to sixteen feet.*

At Milford Haven in Pembrokeshire, at the mouth of the Bristol Channel, the tides rise thirty-six feet; and at King-Road near Bristol, forty-two feet. At Chepstow on the Wye, a small river which opens into the estuary of the Severn, they reach fifty feet, and sometimes sixty-nine, and even seventy-two feet.† A current which sets in on the French coast, to the west of Cape La Hague, becomes pent up by Guernsey, Jersey, and other islands, till the rise of the tide is from twenty to forty-five feet, which last height it attains at Jersey, and at St. Malo, a seaport of Brittany.

There are, however, some coasts where the tides seem to offer an exception to the rule above mentioned; for while there is scarcely any rise in the estuary of the Plata in S. America, there is an extremely high tide on the open coast of Patagonia, farther to the south. Yet even in this region the tides reach their greatest elevation (about fifty feet) in the Straits of Magellan, and so far at least they conform to the general rule.

Currents.—The most extensive and best determined system of currents, is that which has its source in the Indian Ocean under the influence of the trade winds; and which, after doubling the Cape of Good Hope, inclines to the northward, along the western coast of Africa, then crosses the Atlantic, near the equator, and is lost in the Caribbean Sea, yet seems to be again

* The heights of these tides are given on the authority of Captain Hewett, R. N.

† On the authority of Captain Beaufort, R. N.

revived in the current which issues from the gulf of Mexico, by the Straits of Bahama, and flows rapidly in a north-easterly direction by the bank of Newfoundland, towards the Azores.

We learn from the posthumous work of Rennell on this subject, that the Lagullas current, so called from the cape and bank of that name, is formed by the junction of two streams, flowing from the Indian Ocean; the one from the channel of Mozambique, down the south-east coast of Africa; the other, from the ocean at large. The collective stream is from ninety to one hundred miles in breadth, and runs at the rate of from two and a half to more than four miles per hour. It is at length turned westward by the Lagullas bank, which rises from a sea of great depth to within one hundred fathoms of the surface. It must, therefore be inferred, says Rennell, that the current here is more than one hundred fathoms deep, otherwise the main body of it would pass across the bank, instead of being deflected eastward, so as to flow round the Cape of Good Hope. From this cape it flows northward, along the western coast of Africa, taking the name of the South Atlantic current. It then enters the Bight, or Bay of Benin, and is turned westward, partly by the form of the coast there, and partly, perhaps, by the Guinea current, which runs from the north into the same great bay. From the centre of this bay proceeds the Equatorial current, holding a westerly direction across the Atlantic, which it traverses, from the coast of Guinea to that of Brazil, flowing afterwards by the shores of Guiana to the West Indies. The breadth of this current varies from 160 to 450 geographical miles, and its velocity is from twenty-five to seventy-nine

miles per day, the mean rate being about thirty miles. The length of its whole course is about 4000 miles. As it skirts the coast of Guiana, it is increased by the influx of the waters of the Amazon and Orinoco, and by their junction acquires accelerated velocity. After passing the island of Trinidad, it expands, and is almost lost in the Caribbean Sea; but there appears to be a general movement of that sea towards the Mexican gulf, which discharges the most powerful of all currents through the Straits of Florida, where the waters run in the northern part with a velocity of five miles an hour, having a breadth of from thirty-five to fifty miles.

The temperature of the gulf of Mexico is 86°, in summer, or 6° higher than that of the ocean, in the same parallel (25° N. lat.,) and a large proportion of this warmth is retained, even where the stream reaches the 43° N. lat. After issuing from the Straits of Florida, the current runs in a northerly direction to Cape Hatteras, in North Carolina, about 35° N. lat., where it is more than seventy miles broad, and still moves at the rate of seventy-five miles per day. In about the 40° N. lat. it is turned more towards the Atlantic by the extensive banks of Nantucket, and St. George, which are from 200 to 300 feet beneath the surface of the sea; a clear proof that the current exceeds that depth. On arriving near the Azores, the stream widens, and overflows, as it were, forming a large expanse of warm water in the centre of the North Atlantic, over a space of 200 or 300 miles from north to south, and having a temperature of from 8° to 10° Fahr. above the surrounding ocean. The whole area, covered by the gulf water, is estimated by Rennell at 2000 miles in length, and, at a mean, 350 miles in breadth;

an area more extensive than that of the Mediterranean. The warm water has been sometimes known to reach the Bay of Biscay, still retaining five degrees of temperature above that of the adjoining ocean, and a branch of the gulf current occasionally drifts fruits, plants, and wood, the produce of America, and the West Indies, to the shores of Ireland, and the Hebrides.

From the above statements we may understand why Rennell has characterized some of the principal currents as oceanic rivers, which he describes as being from 50 to 250 miles in breadth, and having a rapidity exceeding that of the largest navigable rivers of the continents, and so deep as to be sometimes obstructed, and occasionally turned aside, by banks, the tops of which do not rise within forty, fifty, or even one hundred fathoms of the surface of the sea.*

Greatest velocity of currents.— The ordinary velocity of the principal currents of the ocean is from one to three miles per hour; but when the boundary lands converge, large bodies of water are driven gradually into a narrow space, and then wanting lateral room are compelled to raise their level. Whenever this occurs, their velocity is much increased. The current which runs through the Race of Alderney, between the island of that name and the main land, has a velocity of above eight English miles an hour. Captain Hewett found that in the Pentland Frith the stream, in ordinary spring tides, runs ten miles and a half an hour, and about thirteen miles during violent storms. The greatest velocity of the tidal current through the "Shoots," or New Passage, in the Bristol Channel, is

* Rennell on Currents, p. 58.

fourteen English miles an hour: and Captain King observed, in his recent survey of the Straits of Magellan, that the tide ran at the same rate through the "First Narrows," and about eight geographical miles an hour in other parts of those straits.

Causes of Currents.— That movements of no inconsiderable magnitude should be impressed on an expansive ocean, by winds blowing for many months in one direction, may easily be conceived, when we observe the effects produced in our own seas by the temporary action of the same cause. It is well known that a strong south-west or north-west wind invariably raises the tides to an unusual height along the east coast of England and in the Channel; and that a north-west wind of any continuance causes the Baltic to rise two feet and upwards above its ordinary level. Smeaton ascertained by experiment that, in a canal four miles in length, the water was kept up four inches higher at one end than at the other, merely by the action of the wind along the canal; and Rennell informs us that a large piece of water, ten miles broad, and generally only three feet deep, has, by a strong wind, had its waters driven to one side, and sustained so as to become six feet deep, while the windward side was laid dry.*

As water, therefore, he observes, when pent up so that it cannot escape, acquires a higher level, so, in a place *where it can escape*, the same operation produces a current; and this current will extend to a greater or less distance, according to the force by which it is produced.

Currents flowing alternately in opposite directions

* Rennell on the Channel-current.

are also occasioned by the rise and fall of the tides. The effect of this cause is, as before observed, most striking in estuaries and channels between islands.

A third cause of oceanic currents is evaporation by solar heat, of which the great current setting through the Straits of Gibraltar into the Mediterranean is a remarkable example, and will be fully considered in the next chapter. A stream of colder water also flows from the Black Sea into the Mediterranean. It must happen in many other parts of the world that large quantities of water raised from one tract of the ocean by solar heat, are carried to some other where the vapour is condensed and falls in the shape of rain, and this in flowing back again to restore equilibrium, will cause sensible currents.

These considerations naturally lead to the inquiry whether the level of those seas out of which currents flow is higher than that of seas into which they flow. Arago is of opinion that, so far as observations have gone, there are no exact proofs of any such difference of level. At the same time he admits the important and remarkable fact that the level of the Mediterranean near Alexandria is lower by 26 feet 6 inches than the Red Sea near Suez at low water, and about 30 feet lower than the Red Sea at the same place at high water. This result was obtained during the French expedition to Egypt, from the measurements of M. Lepère.*

It was formerly imagined that there was an equal, if not greater diversity, in the relative levels of the Atlantic and Pacific, on the opposite sides of the isthmus of Panama. But the levellings carried across

* An. du Bureau des Long. pour l'an 1836.

that isthmus by Mr. Lloyd, in 1828, to ascertain the relative height of the Pacific Ocean at Panama, and of the Atlantic at the mouth of the river Chagres, have shown, that the difference of mean level between those oceans is not considerable, and contrary to expectation the difference which does exist is in favour of the greater height of the Pacific. According to the result of this survey, on which great dependence may be placed, the mean height of the Pacific is three feet and a half, or 3.52 above the Atlantic, if we assume the mean level of a sea to coincide with the mean between the extremes of the elevation and depression of the tides; for between the extreme levels of the greatest tides in the Pacific, at Panama, there is a difference of 27.44 feet: and at the usual spring tides 21.22 feet: whereas at Chagres this difference is only 1.16 feet, and is the same at all seasons of the year.

The tides, in short, in the Caribbean Sea are scarcely perceptible, not equalling those in some parts of the Mediterranean, whereas the rise is very high in the Bay of Panama; so that the Pacific is at high tide lifted up several feet above the surface of the Gulf of Mexico, and then at low water let down as far below it.* But astronomers are agreed that, on mathematical principles, the rise of the tidal wave above the mean level of a particular sea must be greater than the fall below it; and although the difference has been hitherto supposed insufficient to cause an appreciable error, it is, nevertheless, worthy of observation, that the error, such as it may be, would tend to reduce the small difference, now inferred, from the observations of Mr. Lloyd, to exist between the levels of the two oceans.

* Phil. Trans. 1830, p. 59.

There is still another way in which heat and cold must occasion great movements in the ocean, a cause to which, perhaps, currents are principally due. It is now ascertained that there is in sea water no point as in fresh water, at which an increase of cold causes the fluid to begin again to expand. In the ocean, therefore, whenever the temperature of the surface is lowered, condensation takes place, and the superficial water, having its specific gravity increased, falls to the bottom, upon which lighter water rises immediately and occupies its place. When this circulation of ascending and descending currents has gone on for a certain time in high latitudes, the inferior parts of the sea are made to consist of colder or heavier fluid than the corresponding depths of the ocean between the tropics. If there be a free communication, if no chain of submarine mountains divide the polar from the equatorial basins, a horizontal movement will arise by the flowing of colder water from the poles to the equator, and there will then be a reflux of warmer superficial water from the equator to the poles. A well-known experiment has been adduced to elucidate this mode of action in explanation of the "trade winds."* If a long trough, divided in the middle by a sluice or partition, have one end filled with water and the other with quicksilver, both fluids will remain quiet so long as they are divided; but when the sluice is drawn up, the heavier fluid will rush along the bottom of the trough, while the lighter, being displaced, will rise, and, flowing in an opposite direction, spread itself at

* See Capt. B. Hall's clear Explanation of the Theory of the Trade Winds, Fragments of Voyages, second series, vol. i., and his letter in the Appendix to Daniell's Meteorology.

the top. In like manner the expansion and contraction of sea-water by heat and cold have a tendency to set under currents in motion from the poles to the equator, and to cause counter-currents at the surface which are impelled in a direction contrary to that of the prevailing trade winds. The geographical and other circumstances being very complicated, we cannot expect to trace separately the movements due to each cause, but must be prepared for many anomalies, especially as the configuration of the bed of the ocean must often modify and interfere with the course of the inferior currents, as much as the position and form of continents and islands alter the direction of those on the surface. Thus on sounding at great depths in the Mediterranean, Captains Berard and D'Urville have found that the cold does not increase in a high ratio as in the tropical regions of the ocean, the thermometer remaining fixed at about 55° F. between the depths of 1000 and 6000 feet. This might have been anticipated, as Captain Smyth in his survey had shown that the deepest part of the Straits of Gibraltar is only 1320 feet, so that a submarine barrier exists there which must prevent the influx of any under-current of the ocean cooled by polar ice.

Each of the four causes above mentioned, the wind, the tides, evaporation, and the expansion and contraction of water by heat and cold, may be conceived to operate independently of the others, and although the influence of all the rest were annihilated. But there is another cause, the rotation of the earth on its axis, which can only come into play when the waters have already been set in motion by some one or all of the forces above described, and when the direction of the

current so raised happens to be from south to north, or from north to south.

The principle on which this cause operates is probably familiar to the reader, as it has long been recognized in the case of the trade winds. Without enlarging, therefore, on the theory, it will be sufficient to offer an example of the mode of action alluded to. When a current flows from the Cape of Good Hope towards the Gulf of Guinea, it consists of a mass of water, which, on doubling the Cape, in lat. 35°, has a rotatory velocity of about 800 miles an hour; but when it reaches the line, it arrives at a parallel where the surface of the earth is whirled round at the rate of 1000 miles an hour, or about 200 miles faster.* If this great mass of water was transferred suddenly from the higher to the lower latitude, the deficiency of its rotatory motion, relatively to the land and water with which it would come into juxtaposition, would be such as to cause an apparent motion of the most rapid kind (of no less than 200 miles an hour) from east to west.

In the case of such a sudden transfer, the eastern coast of America, being carried round in an opposite direction, might strike against a large body of water with tremendous violence, and a considerable part of the continent might be submerged. This disturbance does not occur, because the water of the stream, as it advances gradually into new zones of the sea which are moving more rapidly, acquires by friction an accelerated velocity. Yet as this motion is not imparted instantaneously, the fluid is unable to keep up with the full speed of the new surface over which it is

* See a table in Capt. Hall's work before cited.

successively brought. Hence, to borrow the language of Herschel, when he speaks of the trade winds, "it lags or hangs back, in a direction opposite to the earth's rotation, that is from east to west *," and thus a current which would have run simply towards the north but for the rotation, may acquire a relative direction towards the west, or become a south-easterly current.

We may next consider a case where the circumstances are the converse of the above. The Gulf stream flowing from about lat, 20° is at first impressed with a velocity of rotation of about 940 miles an hour, and runs to the lat. 40°, where the earth revolves only at the rate of 766 miles, or 174 miles slower. In this case a relative motion of an opposite kind may result; and the current may retain an access of rotatory velocity, tending continually to deflect it eastward.

Thus it will be seen that currents depend like the tides on no temporary or accidental circumstances, but on the laws which preside over the motions of the heavenly bodies. But although the sum of their influence in altering the surface of the earth may be very constant throughout successive epochs, yet the points where these operations are displayed in fullest energy shift perpetually. The height to which the tides rise, and the violence and velocity of currents, depend in a great measure on the actual configuration of the land, the contour of a long line of continental or insular coast, the depth and breadth of channels, the peculiar form of the bottom of seas — in a word, on a combination of circumstances which are made to vary continually by many igneous and aqueous causes,

* Treatise on Astronomy, chap. 3.

and, among the rest, by the tides and currents themselves. Although these agents, therefore, of decay and reproduction are local in reference to periods of short duration, such as those which history embraces, they are nevertheless universal, if we extend our views to a sufficient lapse of ages.

Destroying and transporting Power of Currents.— After these preliminary remarks on the nature and causes of currents, their velocity and direction, we may next consider their action on the solid materials of the earth. We shall find that their effects are, in many respects, strictly analogous to those of rivers. I have already treated, in the third chapter, of the manner in which currents sometimes combine with ice, in carrying mud, pebbles, and large fragments of rock to great distances. Their operations are more concealed from our view than those of rivers, but extend over wider areas, and are therefore of more geological importance.

Waste of the British Coasts.— Shetland Islands.— If we follow the eastern and southern shores of the British islands, from our Ultima Thule in Shetland to the Land's End in Cornwall, we shall find evidence of a series of changes since the historical era, very illustrative of the kind and degree of force exerted by tides and currents, co-operating with the waves of the sea. In this survey we shall have an opportunity of tracing their joint power on islands, promontories, bays, and estuaries; on bold, lofty cliffs, as well as on low shores; and on every description of rock and soil, from granite to blown sand.

The northernmost group of the British islands, the Shetland, are composed of a great variety of rocks, including granite, gneiss, mica-slate, serpentine, green-

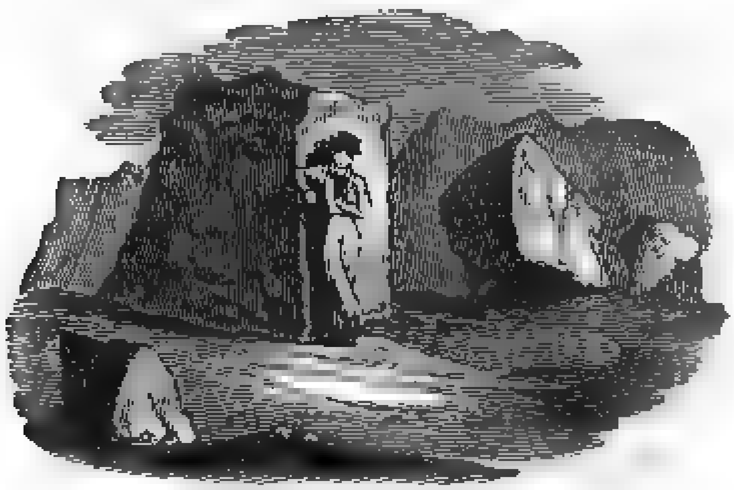
stone, and many others, with some secondary rocks, chiefly sandstone and conglomerate. These islands are exposed continually to the uncontrolled violence of the Atlantic, for no land intervenes between their western shores and America. The prevalence, therefore, of strong westerly gales causes the waves to be sometimes driven with irresistible force upon the coast, while there is also a current setting from the north. The spray of the sea aids the decomposition of the rocks, and prepares them to be breached by the mechanical force of the waves. Steep cliffs are hollowed out into deep caves and lofty arches; and almost every promontory ends in a cluster of rocks, imitating the forms of columns, pinnacles, and obelisks.

Drifting of large Masses of Rock.—Modern observations show that the reduction of continuous tracts to such insular masses is a process in which nature is still actively engaged. "The Isle of Stenness," says Dr. Hibbert, "presents a scene of unequalled desolation. In stormy winters, huge blocks of stones are overturned or are removed from their native beds, and hurried up a slight acclivity to a distance almost incredible. In the winter of 1802, a tabular-shaped mass, eight feet two inches by seven feet, and five feet one inch thick, was dislodged from its bed, and removed to a distance of from eighty to ninety feet. I measured the recent bed from which a block had been carried away the preceding winter (A. D. 1818,) and found it to be seventeen feet and a half by seven feet, and the depth two feet eight inches. The removed mass had been borne to a distance of thirty feet, when it was shivered into thirteen or more lesser fragments, some of which were carried still farther, from 30 to 120 feet. A block, nine feet two inches by six feet

and a half, and four feet thick, was hurried up the acclivity to a distance of 150 feet." *

At Northmavine, also, angular blocks of stone have been removed in a similar manner to considerable distances by the waves of the sea, some of which are represented in the annexed figure.†

Fig. 18.



Stony fragments drifted by the sea. Northmavine, Shetland.

Effects of Lightning.—In addition to numerous examples of masses detached and driven by the waves, tides, and currents from their place, some remarkable effects of lightning are recorded in these isles. At Funzie, in Fetlar, about the middle of the last century, a rock of mica-schist, 105 feet long, ten feet broad, and in some places four feet thick, was in an instant torn by a flash of lightning from its bed, and broken into three large, and several smaller, fragments. One of

* Descrip. of Shetland Islands, p. 527. Edin. 1822.

† For this and the three following representations of rocks in the Shetland Isles, I am indebted to Dr. Hibbert's work before cited, which is rich in antiquarian and geological research.

these, twenty-six feet long, ten feet broad, and four feet thick, was simply turned over. The second, which was twenty-eight feet long, seventeen broad, and five feet in thickness, was hurled across a high point to the distance of fifty yards. Another broken mass, about forty feet long, was thrown still farther, but in the same direction, quite into the sea. There were also many smaller fragments scattered up and down.*

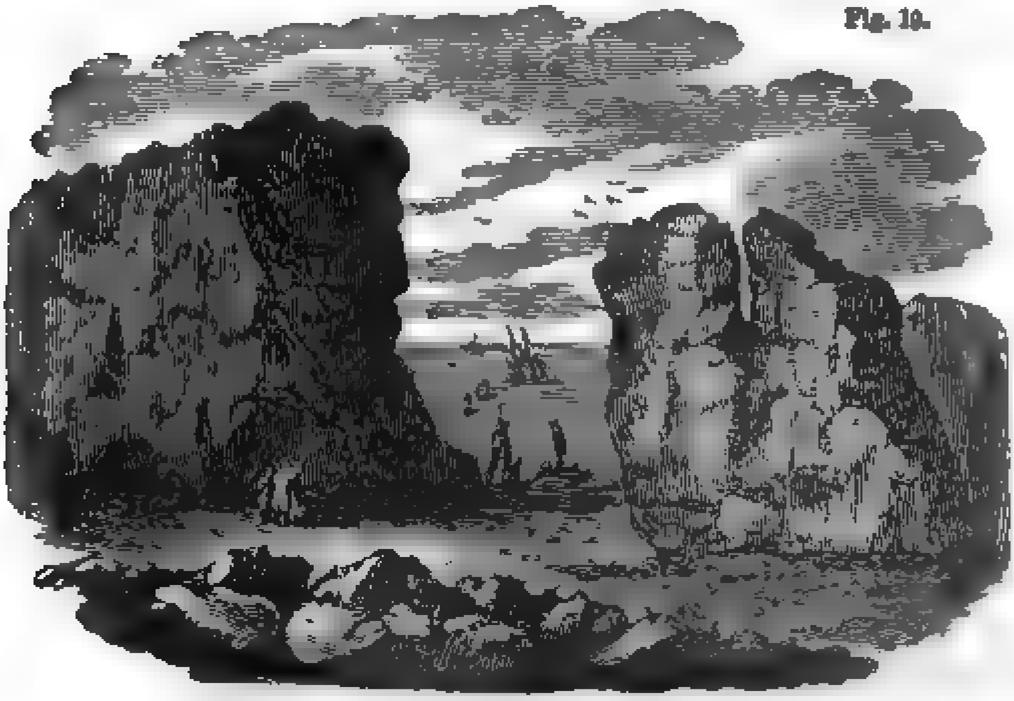
When we thus see electricity co-operating with the violent movements of the ocean in heaping up piles of shattered rocks on dry land, and beneath the waters, we cannot but admit that a region which shall be the theatre, for myriads of ages, of the action of such disturbing causes, might present, at some future period, if upraised far above the bosom of the deep, a scene of havoc and ruin that may compare with any now found by the geologist on the surface of our continents.

In some of the Shetland Isles, as on the west of Meikle Roe, dikes, or veins of soft granite, haye mouldered away; while the matrix in which they were inclosed, being of the same substance, but of a firmer texture, has remained unaltered. Thus, long narrow ravines, sometimes twenty feet wide, are laid open, and often give access to the waves. After describing some huge cavernous apertures into which the sea flows for 250 feet in Roeness, Dr. Hibbert, writing in 1822, enumerates other ravages of the ocean. "A mass of rock, the average dimensions of which may perhaps be rated at twelve or thirteen feet square, and four and a half or five in thickness, was first moved from its bed, about fifty years ago, to a distance of thirty feet, and has since been twice turned over."

* Dr. Hibbert, from MSS. of Rev. George Low, of Fetlar.

Passage forced by the sea through porphyritic rocks. — "But the most sublime scene is where a mural pile of porphyry, escaping the process of disintegration that is devastating the coast, appears to have been left as a sort of rampart against the inroads of the ocean; — the Atlantic, when provoked by wintry gales, batters against it with all the force of real artillery — the waves having, in their repeated assaults, forced themselves an entrance. This breach, named the Grind of the Navir (Fig. 19.,) is widened every winter by the overwhelming surge that, finding a passage through it,

Fig. 19.



Grind of the Navir — Passage forced by the sea through rocks of hard porphyry.

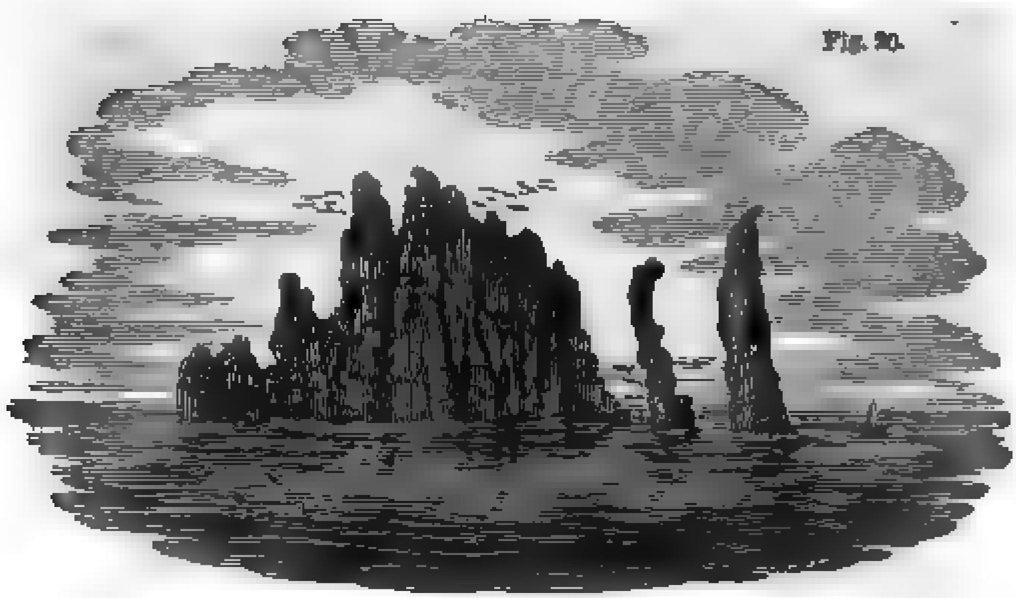
separates large stones from its sides, and forces them to a distance of no less than 180 feet. In two or three spots, the fragments which have been detached are brought together in immense heaps, that appear as an

accumulation of cubical masses, the product of some quarry."*

It is evident, from this example, that although the greater indestructibility of some rocks may enable them to withstand, for a longer time, the action of the elements, yet they cannot permanently resist. There are localities in Shetland, in which rocks of almost every variety of mineral composition are suffering disintegration; thus the sea makes great inroads on the clay slate of Fitfel Head, on the serpentine of the Vord Hill in Fetlar, and on the mica-schist of the Bay of Triesta, on the east coast of the same island, which decomposes into angular blocks. The quartz rock on the east of Walls, and the gneiss and mica-schist of Garthness, suffer the same fate.

Destruction of Islands. — Such devastation cannot be incessantly committed for thousands of years without dividing islands, until they become at last mere

Fig. 20.



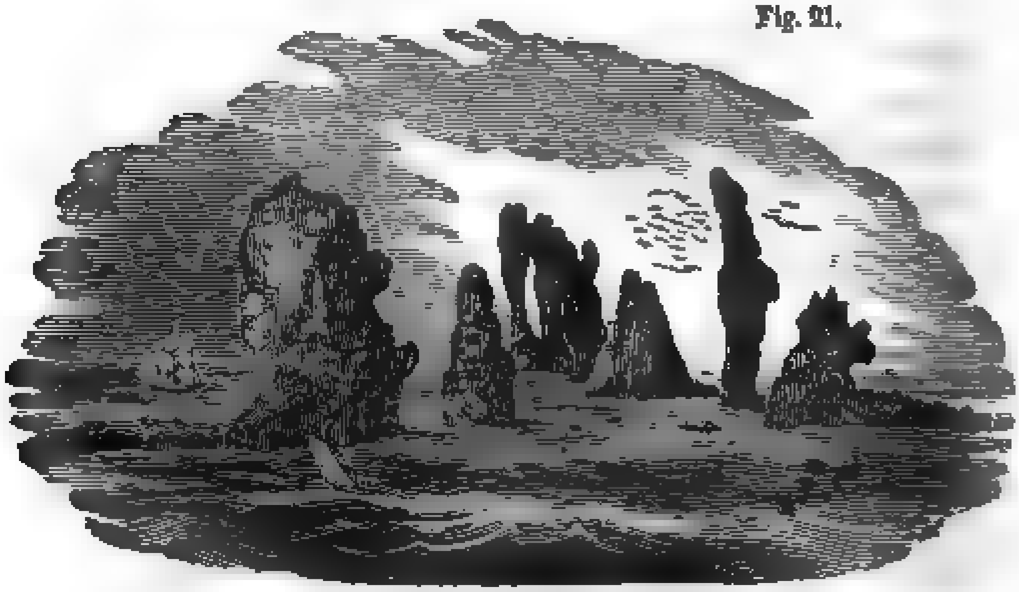
Granitic rocks named the Drongs, between Papa Stour and Hillswick Ness.

* Hibbert, p. 528.

clusters of rocks, the last shreds of masses once continuous. To this state many appear to have been reduced, and innumerable fantastic forms are assumed by rocks adjoining these islands, to which the name of Drongs is applied, as it is to those of similar shape in Feroe.

The granitic rocks (Fig. 20.) between Papa Stour and Hillswick Ness afford an example. A still more singular cluster of rocks is seen to the south of Hillswick Ness (Fig. 21.), which presents a variety of forms as viewed from different points, and has often been likened to a small fleet of vessels with spread sails.* We may imagine that in the course of time Hillswick

Fig. 21.



Granitic rocks to the south of Hillswick Ness, Shetland.

Ness itself may present a similar wreck, from the unequal decomposition of the rocks whereof it is composed, consisting of gneiss and mica-schist, traversed in all directions by veins of felspar-porphyry.

* Hibbert, p. 519.

Midway between the groups of Shetland and Orkney is Fair Island, said to be composed of sandstone with high perpendicular cliffs. The current runs with such velocity, that during a calm, and when there is no swell, the rocks on its shores are white with the foam of the sea driven against them. The Orkneys, if carefully examined, would probably illustrate our present topic as much as the Shetland group. The north-east promontory of Sanda, one of these islands, has been cut off in modern times by the sea, so that it became what is now called Start Island, where a light-house was erected in 1807, since which time the new strait has grown broader.

East Coast of Scotland.— To pass over to the main land of Scotland, we find that in Inverness-shire there have been inroads of the sea at Fort George, and others in Morayshire, which have swept away the old town of Findhorn. On the coast of Kincardineshire, an illustration was afforded, at the close of the last century, of the effect of promontories in protecting a line of low-shore. The village of Mathers, two miles south of Johnshaven, was built on an ancient shingle beach, protected by a projecting ledge of limestone rock. This was quarried for lime to such an extent that the sea broke through, and in 1795 carried away the whole village in one night, and penetrated 150 yards inland, where it has maintained its ground ever since, the new village having been built farther inland on the new shore. In the Bay of Montrose, we find the North Esk and the South Esk rivers pouring annually into the sea large quantities of sand and pebbles, yet they have formed no deltas; for the waves aided by the current, setting across their mouths, sweep away all

the materials. Considerable beds of shingle, brought down by the North Esk, are seen along the beach.

Proceeding southwards, we learn that at Arbroath, in Forfarshire, which stands on a rock of red sandstone, gardens and houses have been carried away since the commencement of the present century by encroachments of the sea. It had become necessary before 1828 to remove the lighthouses, at the mouth of the estuary of the Tay, in the same county, at Button Ness, which were built on a tract of blown sand, the sea having encroached for three quarters of a mile.

Force of Waves and Currents in Estuaries.—The combined power which waves and currents can exert in *estuaries* (a term which I confine to bays entered both by rivers and the tides of the sea) was remarkably exhibited during the building of the Bell Rock Lighthouse, off the mouth of the Tay. The Bell Rock is a sunken reef, consisting of red sandstone, being from twelve to sixteen feet under the surface at high water, and about twelve miles from the mainland. At the distance of 100 yards, there is a depth, in all directions, of two or three fathoms at low water. In 1807, during the erection of the lighthouse, six large blocks of granite, which had been landed on the reef, were removed by the force of the sea, and thrown over a rising ledge to the distance of twelve or fifteen paces; and an anchor, weighing about 22 cwt., was thrown up upon the rock.* Mr. Stevenson informs us, moreover, that drift stones, measuring upwards of thirty cubic feet, or more than two tons weight, have, during storms, been often thrown upon the rock from the deep water.†

* Account of the Erection of the Bell Rock Lighthouse, p. 163.

† Ed. Phil. Journ. vol. iii. p. 54. 1820.

Submarine Forests.— Among the proofs that the sea has encroached on the land bordering the estuary of the Tay, Dr. Fleming has mentioned a submarine forest which has been traced for several miles along the northern shore of the county of Fife.* But subsequent surveys seems to have shown that the bed of peat containing tree roots, leaves, and branches, now occurring at a lower level than the Tay, must have come into its present position by a general sinking of the ground on which the forest grew. The peat bed alluded to is not confined, says Mr. Buist, to the present channel of the Tay, but extends far beyond it, and is covered by stratified clay from fifteen to twenty-five feet in thickness, in the midst of which, in some places, is a bed full of sea shells.† Recent discoveries having established the fact that upward and downward movements have effected our island since the general coast-line had nearly acquired its present shape, we must hesitate before we attribute any given change to a single cause, such as the local encroachment of the sea upon low land.

On the coast of Fife, at St. Andrew's, a tract of land, said to have intervened between the castle of Cardinal Beaton and the sea, has been entirely swept away, as were the last remains of the Priory of Crail, in the same county, in 1803. On both sides of the Frith of Forth, land has been consumed; at North Berwick in particular, and at Newhaven, where an arsenal and dock, built in the reign of James IV., in the fifteenth century, has been overflowed.

East Coast of England. — If we now proceed to the English coast, we find records of numerous lands hav-

* Quart. Journ. of Sci., &c., No. XIII. *N. S.* March, 1830.

† Buist, Quart. Journ. of Agricult., No. XLV. p. 34, June, 1839.

ing been destroyed in Northumberland, as those near Bamborough and Holy Island, and at Tynemouth Castle, which now overhangs the sea, although formerly separated from it by a strip of land. At Hartlepool, and several other parts of the coast of Durham composed of magnesian limestone, the sea has made considerable inroads.

Coast of Yorkshire. — Almost the whole coast of Yorkshire, from the mouth of the Tees to that of the Humber, is in a state of gradual dilapidation. That part of the cliffs which consists of lias, the oolite series, and chalk, decays slowly. They present abrupt and naked precipices, often 300 feet in height; and it is only at a few points that the grassy covering of the sloping talus marks a temporary relaxation of the erosive action of the sea. The chalk cliffs are worn into caves and needles in the projecting headland of Flamborough, where they are decomposed by the salt spray, and slowly crumble away. But the waste is more rapid between that promontory and Spurn Point, or the coast of Holderness, as it is called, a tract consisting of beds of clay, gravel, sand, and chalk rubble. The irregular intermixture of the argillaceous beds causes many springs to be thrown out, and this facilitates the undermining process, the waves beating against them, and a strong current setting chiefly from the north. The wasteful action is very conspicuous at Dimlington Height, the loftiest point in Holderness, where the beacon stands on a cliff 146 feet above high water, the whole being composed of clay, with pebbles scattered through it.*

In the old maps of Yorkshire, we find spots, now

* Phillips's Geology of Yorkshire, p. 61.

sand-banks in the sea, marked as the ancient sites of the towns and villages of Auburn, Hartburn, and Hyde. "Of Hyde," says Pennant, "only the tradition is left; and near the village of Hornsea, a street called Hornsea Beck has long since been swallowed." * Owthorne and its church have also been in great part destroyed, and the village of Kilnsea; but these places are now removed farther inland. The annual rate of encroachment at Owthorne for several years preceding 1830 is stated to have averaged about four yards.† Not unreasonable fears are entertained that at some future time the Spurn Point will become an island, and that the ocean, entering into the estuary of the Humber, will cause great devastation.‡ Pennant, after speaking of the silting up of some ancient ports in that estuary, observes, "But, in return, the sea has made most ample reprisals; the site, and even the very names of several places, once towns of note upon the Humber, are now only recorded in history; and Ravensper was at one time a rival to Hull (Madox, Ant. Exch. i. 422.), and a port so very considerable in 1332, that Edward Baliol and the confederated English Barons sailed from hence to invade Scotland; and Henry IV., in 1399, made choice of this port to land at, to effect the deposal of Richard II.; yet the whole of this has long since been devoured by the merciless ocean: extensive sands, dry at low water, are to be seen in their stead." §

Pennant describes Spurn Head as a promontory in the form of a sickle, and says the land, for some miles

* Arctic Zoology, vol. i. p. 10. Introduction.
† For this information I am indebted to Mr. Phillips of York
‡ Phillips's Geology of Yorkshire, p. 60.
§ Arct. Zool. vol. i. p. 13. Introduction.

to the north, was "perpetually preyed on by the fury of the German Sea, which devours whole acres at a time, and exposes on the shores considerable quantities of beautiful amber." *

According to Bergmann, a strip of land, with several villages, was carried away near the mouth of the Humber in 1475.

Lincolnshire. — The maritime district of Lincolnshire consists chiefly of lands that lie below the level of the sea, being protected by embankments. Great parts of this fenny tract were, at some unknown period, a woody country, but were afterwards inundated, and are now again recovered from the sea. Some of the fens were embanked and drained by the Romans; but after their departure the sea returned, and large tracts were covered with beds of silt containing marine shells, now again converted into productive lands. Many dreadful catastrophes are recorded by incursions of the sea, whereby several parishes have been at different times overwhelmed.

It has been lately proposed by Sir John Rennie and others to rescue from the dominion of the sea a large part of what is called "the Wash," between the counties of Lincoln and Norfolk. The plan for accomplishing this object consists in deepening and straightening the channels of the rivers Ouze, Nene, Witham, and Welland, all of which are to be confined between well-formed banks, and united into one grand channel in the centre of the Wash. The land already gained by similar operations since the middle of the seventeenth century is of vast extent, and the additional space which the projectors hope to reclaim on the opposite

* Arct. Zool. vol. i. p. 13. Introduction.

shores of Lincoln and Norfolk will amount to 150,000 acres, and be half as large again as the county of Rutland in area.*

So great is the quantity of mud suspended in the tidal waters of the rivers entering the Wash, that the accumulation of soil by "warping," wherever the force of the winds and currents can be checked, is surprisingly rapid. Thus, for example, when a portion of the old channel of the Ouze, containing 800 acres, was deserted by an alteration of the drainage, it was warped up, without any artificial aid, to the height of twenty-five feet in five or six years.†

Norfolk. — We come next to the cliffs of Norfolk and Suffolk, where the decay is in general incessant and rapid. At Hunstanton, on the north, the undermining of the lower arenaceous beds at the foot of the cliff causes masses of red and white chalk to be precipitated from above. Between Hunstanton and Weybourne, low hills, or dunes, of blown sand, are formed along the shore, from fifty to sixty feet high. They are composed of dry sand, bound in a compact mass by the long creeping roots of the plant called Marram (*Arundo arenaria*). Such is the present set of the tides, that the harbours of Clay, Wells, and other places, are securely defended by these barriers; affording a clear proof that it is not the strength of the material at particular points that determines whether the sea shall be progressive or stationary, but the general contour of the coast.

The waves constantly undermine the low chalk cliffs, covered with sand and clay, between Weybourne and

* Sir J. Rennie, Report on River Ouze Outfall improvement, p. 13. July, 1839.

† Ibid. p. 9.

Sherringham, a certain portion of them being annually removed. At the latter town I ascertained, in 1829, some facts which throw light on the rate at which the sea gains upon the land. It was computed, when the present inn was built, in 1805, that it would require seventy years for the sea to reach the spot: the mean loss of land being calculated, from previous observations, to be somewhat less than one yard annually. The distance between the house and the sea was fifty yards; but no allowance was made for the slope of the ground being *from* the sea, in consequence of which, the waste was naturally accelerated every year, as the cliff grew lower, there being at each succeeding period less matter to remove when portions of equal area fell down. Between the years 1824 and 1829, no less than seventeen yards were swept away, and only a small garden was then left between the building and the sea. There was in 1829, a depth of twenty feet (sufficient to float a frigate) at one point in the harbour of that port, where, only forty-eight years before, there stood a cliff fifty feet high, with houses upon it! If once in half a century an equal amount of change were produced suddenly by the momentary shock of an earthquake, history would be filled with records of such wonderful revolutions of the earth's surface; but, if the conversion of high land into deep sea be gradual, it excites only local attention. The flag-staff of the Preventive Service station, on the south side of this harbour, was thrice removed inland between the years 1814 and 1829, in consequence of the advance of the sea.

Farther to the south we find cliffs, composed, like those of Holderness before mentioned, of alternating strata of blue clay, gravel, loam, and fine sand. Al-

though they sometimes exceed 300 feet in height, the havoc made on the coast is most formidable. The whole site of ancient Cromer now forms part of the German Ocean, the inhabitants having gradually retreated inland to their present situation, from whence the sea still threatens to dislodge them. In the winter of 1825, a fallen mass was precipitated from near the lighthouse, which covered twelve acres, extending far into the sea, the cliffs being 250 feet in height.* The undermining by springs has sometimes caused large portions of the upper part of the cliffs, with houses still standing upon them, to give way, so that it is impossible, by erecting breakwaters at the base of the cliffs, permanently to ward of the danger.

On the same coast, says Mr. R. C. Taylor, the ancient villages of Shipden, Wimpwell, and Eccles have disappeared; several manors and large portions of neighbouring parishes having, piece after piece, been swallowed up; nor has there been any intermission, from time immemorial, in the ravages of the sea along a line of coast twenty miles in length, in which these places stood.† Of Eccles, however, a monument still remains in the ruined tower of the old church, which is half buried in the dunes of sand within a few paces (60?) of the sea-beach (fig. 22.). So early as 1605 the inhabitants petitioned James I. for a reduction of taxes, as 300 acres of land, and all their houses, save fourteen, had then been destroyed by the sea. Not one half that number of acres now remains in the parish, and hills of blown sand now occupy the site of the houses which were still extant in 1605. When I visited the spot in 1839, the sea was fast encroaching

* Taylor's Geology of East Norfolk, p. 32.

† Ibid.

on the sand hills, and had lain open on the beach the foundations of a house fourteen yards square, the upper part of which had evidently been pulled down before it had been buried under sand. The body of the church has also been long buried, but the tower still remains visible.

Fig. 22.

Tower of the buried Church of Eccles, Norfolk.

The inland slope of the hills of blown sand is shown in this view, with the lighthouse of Hasborough in the distance.

Hills of blown sand, between Eccles and Winterton, have barred up and excluded the tide for many hundred years from the mouths of several small estuaries; but there are records of nine breaches, from 20 to 120 yards wide, having been made through these, by which immense damage was done to the low grounds in the interior. A few miles south of Happisburgh, also, are hills of blown sand, which extend to Yarmouth. These *dunes* afford a temporary protection to the coast, and

an inland cliff about a mile long, at Winterton, shows clearly that at that point the sea must have penetrated formerly farther than at present.

Silting up of Estuaries. — At Yarmouth, the sea has not advanced upon the sands in the slightest degree since the reign of Elizabeth. In the time of the Saxons, a great estuary extended as far as Norwich, which city is represented, even in the thirteenth and fourteenth centuries, "situated on the banks of an arm of the sea." The sands whereon Yarmouth is built, first became firm and habitable ground about the year 1008, from which time a line of dunes has gradually increased in height and breadth, stretching across the whole entrance of the ancient estuary, and obstructing the ingress of the tides so completely, that they are only admitted by the narrow passage which the river keeps open, and which has gradually shifted several miles to the south. The ordinary tides at the river's mouth rise, at present, only to the height of three or four feet, the spring tides to about eight or nine.

By the exclusion of the sea, thousands of acres in the interior have become cultivated lands; and, exclusive of smaller pools, upwards of sixty fresh-water lakes have been formed, varying in depth from fifteen to thirty feet, and in extent from one acre to twelve hundred.* The Yare, and other rivers, frequently communicate with these sheets of water; and thus they are liable to be filled up gradually with lacustrine and fluviatile deposits, and to be converted into land covered with forests. Yet it must not be imagined, that the acquisition of new land fit for cultivation in Norfolk and Suffolk indicates any permanent growth

* Taylor's Geology of East Norfolk, p. 10.

of the eastern limits of our island, to compensate its reiterated losses. No *delta* can form on such a shore.

Immediately off Yarmouth, and parallel to the shore, is a great range of sand-banks, the shape of which varies slowly from year to year, and often suddenly after great storms. Captain Hewett, R. N., found in these banks, in 1836, a broad channel sixty-five feet deep, where there was only a depth of four feet during a prior survey in 1822. The sea had excavated to the depth of sixty feet in the course of fourteen years, or perhaps a shorter period. The new channel thus formed serves at present (1838,) for the entrance of ships into Yarmouth Roads; and the magnitude of this change shows how easily a new set of the waves and currents might endanger the submergence of the land gained within the ancient estuary of the Yare.

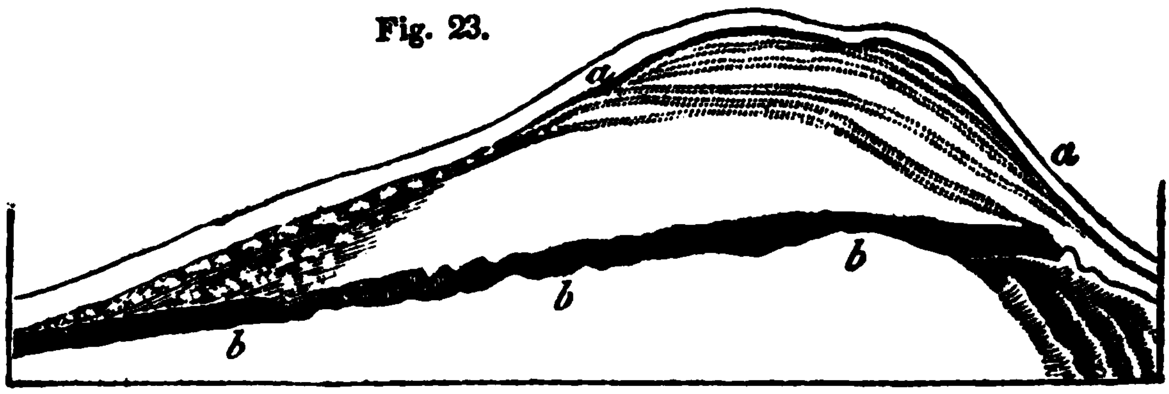
That great banks should be thrown across the mouths of estuaries on our eastern coast, where there is not a large body of river-water to maintain an open channel, is perfectly intelligible, when we bear in mind that the marine current, sweeping along the coast, is charged with the materials of wasting cliffs, and ready to form a bar anywhere, the instant its course is interrupted or checked by any opposing stream. The mouth of the Yare has been, within the last five centuries, diverted about four miles to the south. In like manner it is evident that at some remote period, the river Alde entered the sea at Aldborough, until its ancient outlet was barred up and at length transferred to a point no less than ten miles distant to the south-west. In this case, ridges of sand and shingle, like those of Lowestoff Ness, which will be described by-and-by, have been thrown up between the river and the sea; and an ancient sea-cliff is to be seen, now inland.

It may be asked why the rivers on our east coast are always deflected southwards, although the tidal current flows alternately from the south and north? The cause is to be found in the superior force of what is commonly called "the flood tide from the north," a tidal wave derived from the Atlantic, a small part of which passes eastward up the English Channel, and through the Straits of Dover and then northwards, while the principal body of water, moving much more rapidly in a more open sea, on the western side of Britain, first passes the Orkneys, and then turning, flows down between Norway and Scotland, and sweeps with great velocity along our eastern coast. It is well known that the highest tides on this coast are occasioned by a powerful north-west wind which raises the eastern part of the Atlantic, and causes it to pour a greater volume of water into the German ocean. This circumstance of a violent *off-shore* wind being attended with a rise of the waters, instead of a general retreat of the sea, naturally excites the wonder of the inhabitants of our coast. In many districts they look with confidence for a rich harvest of that valuable manure, the sea-weed, when the north-westerly gales prevail, and are rarely disappointed. The phenomenon is so well calculated to awaken curiosity, that I have heard the cause discussed by peasants and fishermen; and more than once they have hazarded a theory of their own to account for it. The most ingenious idea which I heard suggested was this: a vast body of surface water, say they, is repelled by the wind from the shore, which afterwards returns, in order to restore the level of the sea; by this means a strong under-current is produced, which tears up the weed from the bed of the sea, and casts it ashore. The true explanation,

however, of the phenomenon is doubtless that above mentioned.

Coast of Suffolk.— The cliffs of Suffolk, to which we next proceed, are somewhat less elevated than those of Norfolk, but composed of similar alternations of clay, sand, and gravel. From Gorleston in Suffolk, to within a few miles north of Lowestoff, the cliffs are slowly undermined. Near the last-mentioned town, there is an inland cliff about sixty feet high, the sloping talus of which is covered with turf and heath.

Fig. 23.



*Map of Lowestoff Ness, Suffolk.**

a, a. The dotted lines express a series of sand and shingle, forming the extremity of the triangular space called the Ness.
b, b, b. The dark line represents the inland cliff on which the town of Lowestoff stands, between which and the sea is the Ness.

Between the cliff and the sea is a low, flat tract of sand, called the Ness, nearly three miles long, and for the most part out of reach of the highest tides. The point of the Ness projects from the base of the original cliff to the distance of 660 yards. This accession of land, says Mr. Taylor, has been effected at distinct and distant intervals, by the influence of currents running between the land and a shoal about a mile off Lowestoff, called the Holm Sand. The lines of growth in

* From Mr. R. C. Taylor's Mem., see below.

the Ness are indicated by a series of concentric ridges or embankments inclosing limited areas, and several of these ridges have been formed within the observation of persons now living. A rampart of heavy materials is first thrown up to an unusual altitude by some extraordinary tide, attended with a violent gale. Subsequent tides extend the base of this high bank of shingle, and the interstices are then filled with sand blown from the beach. The Arundo and other marine plants by degrees obtain a footing; and creeping along the ridge, give solidity to the mass, and form in some cases a matted covering of turf. Meanwhile another mound is forming externally, which by the like process rises and gives protection to the first. If the sea forces its way through one of the external and incomplete mounds, the breach is soon repaired. After a while the marine plants within the areas inclosed by these embankments are succeeded by a better species of herbage, affording good pasturage, and the sands become sufficiently firm to support buildings.*

Destruction of Dunwich by the Sea.—The sea undermines the high cliffs near Corton, a few miles north of Lowestoff, as also two miles south of the same town, at Pakefield, a village which has been in part swept away during the present century. From thence to Dunwich the destruction is constant. At the distance of 250 yards from the wasting cliff at Pakefield, where we must suppose land to have existed at no remote period, the sea is sixteen feet deep at low water, and in the roadstead beyond, twenty-four feet. Of the gradual destruction of Dunwich, once the most

* The formation of the Ness is well described by Mr. R. C. Taylor, Phil. Mag., Oct. 1827, p. 297.

considerable seaport on this coast, we have many authentic records. Gardner, in his history of that borough, published in 1754, shows, by reference to documents beginning with Doomsday Book, that the cliffs at Dunwich, Southwold, Eastern, and Pakefield, have been always subject to wear away. At Dunwich, in particular, two tracts of land which had been taxed in the eleventh century, in the time of King Edward the Confessor, are mentioned, in the Conqueror's survey, made but a few years afterwards, as having been devoured by the sea. The losses, at a subsequent period, of a monastery, — at another of several churches, — afterwards of the old port, — then of four hundred houses at once, — of the church of St. Leonard, the high road, town-hall, gaol, and many other buildings, are mentioned, with the dates when they perished. It is stated that, in the sixteenth century, not one quarter of the town was left standing; yet the inhabitants retreating inland, the name was preserved, as has been the case with many other ports, when their ancient site has been blotted out. There is, however, a church, of considerable antiquity, still standing, the last of twelve mentioned in some records. In 1740, the laying open of the churchyard of St. Nicholas and St. Francis, in the sea-cliffs, is well described by Gardner, with the coffins and skeletons exposed to view — some lying on the beach, and rocked —

> "In cradle of the rude imperious surge."

Of these cemeteries no remains can now be seen. Ray also says, "that ancient writings make mention of a wood a mile and a half to the east of Dunwich, the site of which must at present be so far within the sea." *

* Consequences of the Deluge, Phys. Theol. Discourses.

This city, once so flourishing and populous, is now a small village, with about twenty houses, and one hundred inhabitants.

There is an old tradition, "that the tailors sat in their shops at Dunwich, and saw the ships in Yarmouth Bay;" but when we consider how far the coast at Lowestoff Ness projects between these places, we cannot give credit to the tale, which, nevertheless, proves how much the inroads of the sea in times of old had prompted men of lively imagination to indulge their taste for the marvellous.

Gardner's description of the cemeteries laid open by the waves remind us of the scene which has been so well depicted by Bewick,* and of which numerous points on the same coast might have suggested the idea. On the verge of a cliff, which the sea has undermined, are represented the unshaken tower and western end of an abbey. The eastern aisle is gone, and the pillars of the cloister are soon to follow. The waves have almost isolated the promontory, and invaded the cemetery, where they have made sport with the mortal relics, and thrown up a skull upon the beach. In the foreground is seen a broken tombstone, erected, as its legend tells, "to *perpetuate* the memory of one whose name is obliterated, as is that of the county for which he was 'Custos Rotulorum.'" A cormorant is perched on the monument, defiling it, as if to remind some moralizer, like Hamlet, of "the base uses" to which things sacred may be turned. Had this excellent artist desired to satirize certain popular theories of geology, he might have inscribed the stone to the memory of some philosopher who taught "the permanency of

* History of British Birds, vol. ii. p. 220. Ed. 1821.

existing continents" — "the era of repose" — "the impotence of modern causes."

The incursions of the sea at Aldborough were formerly very destructive, and this borough is known to have been once situated a quarter of a mile east of the present shore. The inhabitants continued to build farther inland, till they arrived at the extremity of their property, and then the town decayed greatly; but two sand-banks, thrown up at a short distance, now afford a temporary safeguard to the coast. Between these banks and the present shore, where the current now flows, the sea is twenty-four feet deep on the spot where the town formerly stood.

Continuing our survey of the Suffolk coast to the southward, we find that the cliffs of Bawdsey and Felixtow are foundering continually. It appears that, within the memory of persons now living, the Orwell river continued its course in a more direct line to the sea, and entered to the north instead of the south of the low bank on which Landguard Fort is built.

Essex.—Harwich is said to have owed its rise to the destruction of Orwell, a town which stood on the spot now called "the west rocks," and was overwhelmed by an inroad of the sea since the Conquest. The isthmus on which Harwich stands will probably become an island in about half a century, for the sea by that time may have made a breach near Lower Dover Court, where the cliffs are composed of horizontal beds of London clay containing septaria. They had wasted away considerably between the years 1829 and 1838, at both which periods I examined this coast. In that short interval several gardens and many houses had been swept into the sea, and in April 1838, a whole street was threatened with destruction. The advance

of the sea is much accelerated by the traffic carried on in septaria, which are shipped off to Harwich for cement as fast as they fall down upon the beach, where they become the property of the lord of the manor, who is not lord of the soil on which the buildings stand. These stones, if allowed to remain in heaps on the shore, would break the force of the waves, and retard the conversion of the isthmus into an island, an event which might be followed by the destruction of the town of Harwich.

Among other losses it is recorded, that since the year 1807, a field called the Vicar's Field, which belonged to the living of Harwich, has been overwhelmed;* and in the year 1820 there was a considerable space between the battery at Harwich, built in the beginning of the present century, and the sea; part of the fortification had been swept away in 1829, and the rest then overhung the water.

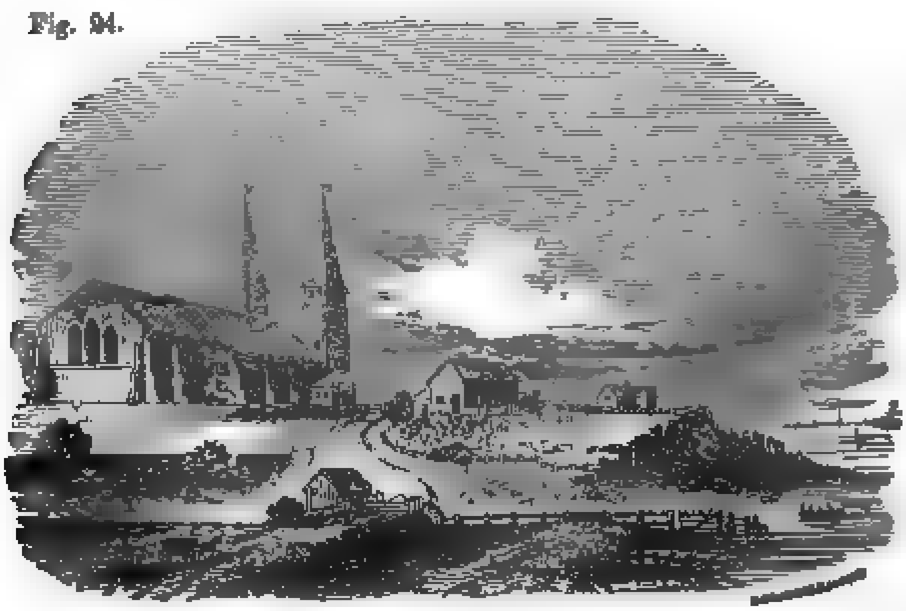
At Walton Naze, in the same county, the cliffs, composed of London clay, capped by the shelly sands of the crag, reached the height of about 100 feet, and are annually undermined by the waves. The old churchyard of Walton has been washed away, and the cliffs to the south are constantly disappearing.

Kent.—Isle of Sheppey.—On the coast bounding the estuary of the Thames, there are numerous examples both of the gain and loss of land. The Isle of Sheppey, which is now about six miles long by four in breadth, is composed of London clay. The cliffs on the north, which are from sixty to eighty feet high, decay rapidly, fifty acres having been lost in twenty years, between 1810 and 1830. The church at Minster, now near the coast, is said to have been in the middle of

* On authority of Dr. Mitchell, F. G. S.

the island in 1780*; and it has been conjectured that, at the present rate of destruction, the whole isle will be annihilated in about half a century. On the coast of the mainland to the east of Sheppey is Herne Bay; a place still retaining the name of a bay, although it is no longer appropriate, as the waves and currents have swept away the ancient headlands. There was formerly a small promontory in the line of the shoals where the present pier is built, by which the larger bay was divided into two, called the Upper and Lower.†

Fig. 24.



View of Reculver Church, taken in the year 1781.

1. Isle of Sheppey.
2. Ancient chapel now destroyed. The cottage between this chapel and the cliff was demolished by the sea, in 1782.

Still farther east stands the church of Reculver, upon a cliff composed of clay and sand, about twenty feet high. Reculver (Regulvium) was an important military station in the time of the Romans, and appears, from Leland's account, to have been, so late as Henry

* For this information I am indebted to W. Gunnel, Esq.

† On the authority of W. Richardson, Esq., F. G. S.

Fig. 25.

Reculver Church, in 1834.

VIII.'s reign, nearly one mile distant from the sea. In the "Gentleman's Magazine," there is a view of it, taken in 1781, which still represents a considerable space as intervening between the north wall of the churchyard and the cliff.* Some time before the year 1780, the waves had reached the site of the ancient Roman camp, or fortification, the walls of which had continued for several years after they were undermined to overhang the sea, being firmly cemented into one mass. They were eighty yards nearer the sea than the church, and they are spoken of in the "Topographica Britannica," in the year 1780, as having recently fallen down. In 1804, part of the

* Vol. ii. New Series, 1809, p. 801.

churchyard with some adjoining houses was washed away, and the ancient church, with its two lofty spires, a well known land-mark, was dismantled and abandoned as a place of worship. It is still standing (1834,) but would probably have been annihilated ere this, had not the force of the waves been checked by an artificial causeway of stones and large wooden spiles driven into the sands to break the force of the waves.*

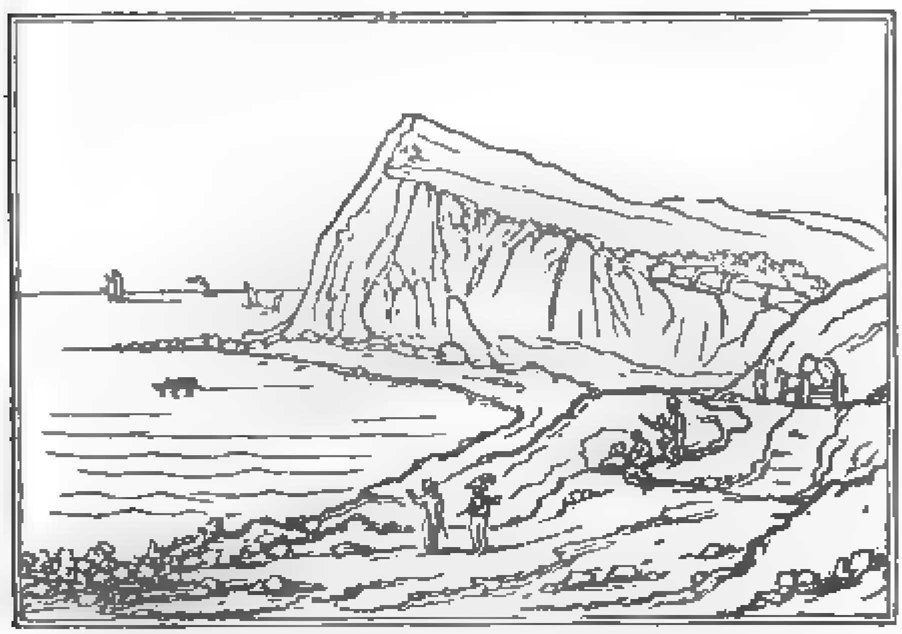
Isle of Thanet.—The isle of Thanet was, in the time of the Romans, separated from the rest of Kent by a navigable channel, through which the Roman fleets sailed on their way to and from London. Bede describes this small estuary as being, in the beginning of the eighth century, three furlongs in breadth; and it is supposed that it began to grow shallow about the period of the Norman conquest. It was so far silted up in the year 1485, that an act was then obtained to build a bridge across it; and it has since become marsh land with small streams running through it. On the coast, Bedlam Farm, belonging to the hospital of that name, lost eight acres in the twenty years preceding 1830, the land being composed of chalk from forty to fifty feet above the level of the sea. It has been computed, that the average waste of the cliff between the North Foreland and the Reculvers, a distance of about eleven miles, is not less than two feet per annum. The chalk cliffs on the south of Thanet, between Ramsgate and Pegwell Bay, have on an average lost three feet per annum for the ten last years (preceding 1830).

Goodwin Sands.—The Goodwin Sands lie opposite this part of the Kentish coast. They are about ten miles in length, and are in some parts three, and, in

* Dr. Mitchell, Proceedings of Geol. Soc. vol. ii. No. 1.

others seven miles distant from the shore; and, for a certain space, are laid bare at low water. That they are a remnant of land, and not "a mere accumulation of sea sand," as Rennell imagined,* may be presumed from the fact that, when the erection of a lighthouse on this shoal was in contemplation by the Trinity Board in the year 1817, it was found, by borings, that the bank consisted of fifteen feet of sand, resting on blue clay. An obscure tradition has come down to us, that the estates of Earl Goodwin, the father of Harold, who died in the year 1053, were situated here, and some have conjectured that they were overwhelmed by the flood mentioned in the Saxon chronicle, *sub anno* 1099. The last remains of an island, consisting, like Sheppey, of clay, may perhaps have been carried away about that time.

Fig. 26.



Shakspeare's Cliff in 1836, seen from the North-east.

There are other records of waste in the county of Kent, as at Deal; and at Dover, where Shakspeare's

* Geog. of Herod. vol. ii. p. 326.

cliff, composed entirely of chalk, has suffered greatly, and continually diminishes in height, the slope of the hill being towards the land. (See fig. 26.) There was an immense landslip from this cliff in 1810, by which Dover was shaken as if by an earthquake, and a still greater one in 1772.* We may suppose, therefore, that the view from the top of the precipice in the year, 1600, when the tragedy of King Lear was written, was more "fearful and dizzy" than it is now.

Straits of Dover.—In proceeding from the northern parts of the German Ocean towards the straits of Dover, the water becomes gradually more shallow, so that in the distance of about two hundred leagues we pass from a depth of 120, to that of 58, 38, 18, and even less than 2 fathoms. The shallowest part follows a line drawn between Romney Marsh and Boulogne. From this point the English Channel again deepens progressively as we proceed westward, so that the Straits of Dover may be said to part two seas.†

Whether England was formerly united with France has often been a favourite subject of speculation. So early as 1605 our countryman Verstegan, in his "Antiquities of the English Nation," observed that many preceding writers had maintained this opinion, but without supporting it by any weighty reasons. He accordingly endeavours himself to confirm it by various arguments, the principal of which are, first, the proximity and identity of the composition of the opposite cliffs and shores of Albion and Gallia, which, whether flat and sandy or steep and chalky, correspond exactly with each other; secondly, the occurrence of

* Dodsley's Ann. Regist. 1772.

† Stevenson, Ed. Phil. Journ. No. v. p. 45., and Dr. Fitton, Geol. Trans., 2d series, vol. iv. plate 9.

a submarine ridge, called "our Lady's Sands," extending from shore to shore at no great depth, and which from its composition appears to be the original basis of the isthmus; thirdly, the identity of the noxious animals in France and England, which could neither have swum across, nor have been introduced by man. Thus no one, he says, would have imported wolves, therefore "these wicked beasts did of themselves pass over."

He supposes the ancient isthmus to have been about six English miles in breadth, composed entirely of chalk and flint, and in some places of no great height above the sea-level. He does not pretend to decide whether the first breach was made by an earthquake, the channel having afterwards been enlarged by the waves, or whether it was cut by the labour of man for a commodious passage, or means of defence, or whether it was occasioned by the gradual encroachments of the sea, which he imagines to have been higher, and to have run with a stronger current on the north-eastern than on the western side of the isthmus.

Cuvier informs us that in 1753 (a century and a half later,) a society at Amiens proposed the question above alluded to as a prize essay, which was gained by the celebrated Desmarest, then a young man. With respect to this essay, it has been justly remarked, in a recent memoir by Mr. Page, that Desmarest borrowed all his arguments from Verstegan, for they are not only the same in number and substance, but are advanced in precisely the same order.*

* See paper read by Mr. Page to Lit. and Phil. Soc. of St. Andrews, Fife Journal, Jan. 17, 1839, and Cuvier's Eloge de Desmarest.

When we consider the state of physical science at the commencement of the seventeenth century, we cannot too much admire the philosophical spirit and acuteness with which Verstegan conducts his argument. The operation of the waves and tides, he says, would have been more powerful when the straits were narrower than now, when they are still destroying cliffs composed of similar materials. He suggests the possible cooperation of earthquakes; and I may mention that there are geological appearances at the base of the cliffs near Dover and Brighton, which indicate oscillations in the relative level of sea and land at a very modern period. We there learn that the chalk itself, originally a marine deposit, has been depressed about 60 feet since its first emergence from the deep, and that the actual cliffs are not the first which have been excavated. These, and perhaps other upward and downward movements, may have taken place as slowly as those now in progress in Sweden and Greenland, and they cannot fail to have greatly assisted the denuding force of "the ocean stream."

Ποταμοιο μεγα σθενος Ωκεανοιο.

Folkstone. — At Folkstone, the sea undermines the chalk and subjacent strata. About the year 1716 there was a remarkable sinking of a tract of land near the sea, so that houses became visible from certain points at sea, and from particular spots on the sea cliffs, from whence they could not be seen previously. In the description of this subsidence in the Phil. Trans. 1716, it is said, "that the land consisted of a solid stony mass (chalk), resting on wet clay (gault), so that it slid forwards towards the sea, just as a ship is launched on tallowed planks." It is also stated that within the

memory of persons then living, the cliff there had been washed away to the extent of ten rods.

Encroachments of the sea at Hythe are also on record; but between this point and Rye there has been a gain of land within the times of history; the rich level tract called Romney Marsh, or Dungeness, about ten miles in width and five in breadth, and formed of silt, having received great accession. It has been necessary, however, to protect it from the sea, from the earliest periods, by embankments, the towns of Lydd and Romney being the only parts of the marsh above the level of the highest tides.* These additions of land are exactly opposite that part of the English Channel where the conflicting tide-waves from the north and south meet; for, as that from the north is, for reasons already explained, the most powerful, they do not neutralize each other's force till they arrive at this distance from the Straits of Dover. Here therefore some portion of the materials drifted from west to east along the shores of Sussex and Kent find at length a resting place.

Rye, situated to the south of Romney marsh, was once destroyed by the sea, but it is now two miles distant from it. The neighbouring town of Winchelsea was destroyed in the reign of Edward I., the mouth of the Rother stopped up, and the river diverted into another channel. In its old bed, an ancient vessel, apparently a Dutch merchantman, was recently found. It was built entirely of oak, and much blackened.† Large quantities of hazel nuts, peat, and wood are found in digging in Romney marsh.

* On the authority of Mr. J. Meryon, of Rye.

† Edin. Journ. of Sci. No. xix. p. 56.

South Coast of England.— To pass over some points near Hastings, where the cliffs have wasted at several periods, we arrive at the promontory of Beachy Head. Here a mass of chalk, three hundred feet in length, and from seventy to eighty in breadth, fell, in the year 1813, with a tremendous crash; and similar slips have since been frequent.*

About a mile to the west of the town of Newhaven the remains of an ancient entrenchment are seen on the brow of Castle Hill. This earth-work, supposed to be Roman, was evidently once of considerable extent and of an oval form, but the greater part has been cut away by the sea. The cliffs, which are undermined here, are high; more than one hundred feet of chalk being covered by tertiary clay and sand, from sixty to seventy feet in thickness. In a few centuries the last vestiges of the plastic clay formation on the southern borders of the chalk of the South Downs on this coast will be annihilated, and future geologists will learn, from historical documents, the ancient geographical boundaries of this group of strata in that direction. On the opposite side of the estuary of the Ouse, on the east of Newhaven harbour, a bed of shingle, composed of chalk flints, derived from the waste of the adjoining cliffs, had accumulated at Seaford for several centuries. In the great storm of November, 1824, this bank was entirely swept away, and the town of Seaford inundated. Another great beach of shingle is now forming from fresh materials.

The whole coast of Sussex has been incessantly encroached upon by the sea from time immemorial; and, although sudden inundations only, which over-

* Webster, Geol. Trans. vol. ii. p. 192. 1st series.

whelmed fertile or inhabited tracts, are noticed in history, the records attest an extraordinary amount of loss. During a period of no more than eighty years, there are notices of about *twenty* inroads, in which tracts of land of from twenty to *four hundred acres* in extent were overwhelmed at once; the value of the tithes being mentioned by Nicholas, in his Taxatio Ecclesiastica.* In the reign of Elizabeth, the town of Brighton was situated on that tract where the chain pier now extends into the sea. In the year 1665 twenty-two tenements had been destroyed under the cliff. At that period there still remained under the cliff 113 tenements, the whole of which were overwhelmed in 1703 and 1705. No traces of the ancient town are now perceptible, yet there is evidence that the sea has merely resumed its ancient position at the base of the cliffs, the site of the old town having been merely a beach abandoned by the ocean for ages.

Hampshire — Isle of Wight.— It would be endless to allude to all the localities on the Sussex and Hampshire coasts where the land has given way; but I may point out the relation which the geological structure of the Isle of Wight bears to its present shape, as attesting that the coast owes its outline to the continued action of the sea. Through the middle of the island runs a high ridge of chalk strata, in a vertical position, and in a direction east and west. This chalk forms the projecting promontory of Culver Cliff on the east, and of the Needles on the west; while Sandown Bay on the one side, and Compton Bay on the other, have been hollowed out of the softer

* Mantell, Geology of Sussex, p. 293.

sands and argillaceous strata, which are inferior, in geological position, to the chalk.

The same phenomena are repeated in the Isle of Purbeck, where the line of vertical chalk forms the projecting promontory of Handfast Point; and Swanage Bay marks the deep excavation made by the waves in the softer strata, corresponding to those of Sandown Bay.

Hurst Castle bank — progressive motion of sea-beaches. — Although the loose pebbles and grains of sand composing any given line of sea-beach are carried sometimes one way sometimes another, they have, nevertheless, an ultimate motion in one particular direction.* Their progress, for example, on the south coast of England is from west to east, which is owing partly to the action of the waves driven eastwards by the prevailing wind, and partly to the current, or the motion of the general body of water caused by the tides and winds. The force of the waves gives motion to pebbles which the velocity of the currents alone would be unable to carry forwards; but as the pebbles are finally reduced to sand or mud, by continued attrition, they are brought within the influence of a current; and this cause must determine the course which the main body of matter derived from wasting cliffs will eventually take.

It appears, from the observations of Mr. Palmer and others, that if a pier or groin be erected anywhere on our southern or south-eastern coast to stop the progress of the beach, a heap of shingle soon collects on the western side of such artificial barriers. The pebbles continue to accumulate till they rise as high as the pier

* See Palmer on Shingle Beaches, Phil. Trans. 1834, p. 568.

or groin, after which they pour over in great numbers during heavy gales.*

The western entrance of the Channel, called the Solent, is crossed for more than two thirds of its width by the shingle-bank of Hurst Castle, which is about seventy yards broad and twelve feet high, presenting an inclined plane to the west. This singular bar consists of a bed of rounded chalk flints, resting on a submarine argillaceous base. The flints and a few other pebbles, intermixed, are exclusively derived from the waste of Hordwell, and other cliffs to the westward, where tertiary strata, capped with a covering of broken chalk flints, from five to fifty feet thick, are rapidly undermined. In the great storm of November, 1824, this bank of shingle was moved bodily forwards for forty yards towards the north-east; and certain spiles, which served to mark the boundaries of two manors, were found after the storm on the opposite side of the bar. At the same time many acres of pasture land were covered by shingle, on the farm of Westover, near Lymington.

The cliffs between Hurst Shingle Bar and Christchurch are undermined continually. Within the memory of persons now living, it has been necessary thrice to remove the coast-road farther inland. The tradition, therefore, is probably true, that the church of Hordwell was once in the middle of that parish, although now very near the sea. The promontory of Christchurch Head gives way slowly. It is the only point between Lymington and Poole Harbour, in Dorsetshire, where any hard stony masses occur in the

* Groins are formed of spiles and wooden planks, or of faggots staked down; and they are used either to break the force of the waves, or to retain the beach.

cliffs. Five layers of large ferruginous concretions, somewhat like the septaria of the London clay, have occasioned a resistance at this point, to which we may ascribe this headland. In the mean time, the waves have cut deeply into the soft sands and loam of Poole Bay; and, after severe frosts, great landslips take place, which, by degrees, become enlarged into narrow ravines, or chines, as they are called, with vertical sides. One of these chines near Boscomb, has been deepened twenty feet within a few years. At the head of each there is a spring, the waters of which have been chiefly instrumental in producing these narrow excavations, which are sometimes from 100 to 150 feet deep.

Isle of Portland. — The Peninsulas of Purbeck and Portland are continually wasting away. In the latter, the soft argillaceous substratum (Kimmeridge clay) hastens the dilapidation of the superincumbent mass of limestone.

In 1665 the cliffs adjoining the principal quarries in Portland gave way to the extent of one hundred yards, and fell into the sea; and in December, 1734, a slide to the extent of 150 yards occurred on the east side of the isle, by which several skeletons, buried between slabs of stone, were discovered. But a much more memorable occurrence of this nature, in 1792, occasioned probably by the undermining of the cliffs, is thus described in Hutchins's History of Dorsetshire. — "Early in the morning the road was observed to crack: this continued increasing, and before two o'clock the ground had sunk several feet, and was in one continued motion, but attended with no other noise than what was occasioned by the separation of the roots and brambles, and now and then a falling rock. At night it seemed to stop a little, but soon moved again;

and before morning, the ground, from the top of the cliff to the water-side, had sunk in some places fifty feet perpendicular. The extent of ground that moved was about *a mile and a quarter* from north to south, and 600 yards from east to west.

Formation of the Chesil Bank. — Portland is connected with the mainland by the Chesil Bank, a ridge of shingle about seventeen miles in length, and, in most places, nearly a quarter of a mile in breadth. The pebbles forming this immense barrier are chiefly siliceous, all loosely thrown together, and rising to the height of from twenty to thirty feet above the ordinary high-water mark, at that part which is nearest the Isle of Portland. The fundamental rocks whereon the shingle rests are found at the depth of a few yards only below the level of the sea. The formation of that part of the bar which attaches Portland to the mainland, may have been due to an original shoal or reef, or to the set of the tides in the narrow channel, by which the course of the pebbles, which are always coming from the west, has been arrested. It is a singular fact that throughout the Chesil Bank the pebbles diminish gradually in size as we proceed westward, or as we approach the quarter from which they are supplied. Had the case been reversed, we should naturally have attributed the circumstance to the constant wearing down of the pebbles by friction, as they are rolled along a beach seventeen miles in length. We must now suppose that the velocity of the waves, due to the combined influence of the winds and tides, increases gradually from north-west to south-east, which is the direction of the beach. In that case the size of the masses coming from the westward and thrown ashore would be largest where the motion of the water was

most violent. Colonel Reid states that all calcareous stones rolled along from the west are soon ground into sand, and in this form they pass round Portland island.*

The storm of 1824 burst over the Chesil Bank with great fury, and the village of Chesilton, built upon its southern extremity, was overwhelmed, with many of the inhabitants. This same storm carried away part of the Breakwater at Plymouth, and huge masses of rock from two to five tons in weight, were lifted from the bottom of the weather side, and rolled fairly to the top of the pile. One block of limestone, weighing seven tons, was washed round the western extremity of the Breakwater, and carried 150 feet.† It was in the same month, and also during a spring-tide, that a great flood is mentioned on the coast of England, in the year 1099. Florence of Worcester says, "On the third day of the nones of Nov. 1099, the sea came out upon the shore, and buried towns and men very many, and oxen and sheep innumerable." We also read in the Saxon Chronicle, already cited, for the year 1099, "This year eke on St. Martin's mass day, the 11th of Novembre, sprung up so much of the sea flood, and so myckle harm did, as no man minded that it ever afore did, and there was the ylk day a new moon."

Dorsetshire — Devonshire. — At Lyme Regis, in Dorsetshire, the "Church Cliffs," as they are called, consisting of lias about one hundred feet in height, have gradually fallen away, at the rate of one yard a year, since 1800.‡

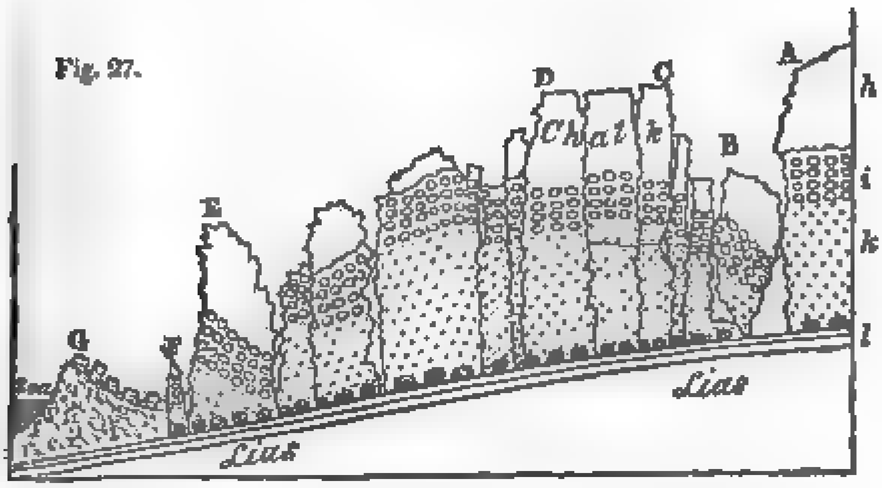
* See Palmer on Motion of Shingle Beaches, Phil. Trans. 1834, p. 568., and Col. Reid on the same, Professional Papers of Royal Engineers, 1838, vol. 2. p. 128.

† De la Beche, Geol. Man. p. 82.

‡ This ground was measured by Dr. Carpenter of Lyme, in

An extraordinary landslip occurred on the 24th of December, 1839, on the coast between Lyme Regis and Axmouth, which has been described by the Rev. W. D. Conybeare, to whose kindness I am indebted for an early communication on the subject. The tract of downs ranging there along the coast is capped by Chalk (*h*, fig. 27.), which rests on sandstone, alternating with chert (*i*), beneath which is more than 100 feet of loose sand (*k*), with concretions at the bottom, and belonging, like *i*, to the Green Sand formation; the whole of the above masses, *h*, *i*, *k*, reposing on retentive beds of clay (*l*), belonging to the Lias, which

Fig. 27.



Landslip, near Axmouth, Dec. 1839. (Rev. W. D. Conybeare.)

A. Tract of Downs still remaining at their original level.
B. New ravine.
C, D. Sunk and fractured strip united to A, before the convulsion.
D, E. Bendon undercliff as before, but more fissured, and thrust forward about fifty feet towards the sea.
F. Pyramidal crag, sunk from seventy to twenty feet in height.
G. New reef upheaved from the sea.

shelves towards the sea. Numerous springs issuing from the loose sand (*k*) have gradually removed portions of it, and thus undermined the superstratum, so

1800, and again in 1829, as I am informed by Miss Mary Anning of Lyme, well known by her discoveries in fossil remains.

as to have caused subsidences at former times, and to have produced a line of undercliff between D and E. In 1839 an excessively wet season had saturated all the rocks with moisture, so as to increase the weight of the incumbent mass, from which the support had already been withdrawn by the action of springs. Thus the superstrata were precipitated into hollows prepared for them, and the adjacent masses of partially undermined rock, to which the movement was communicated, were made to slide down on a slippery basis of watery sand towards the sea. These causes gave rise to a convulsion, which began on the morning of the 24th of December, with a crashing noise; and, on the evening of the same day, fissures were seen opening in the ground, and the walls of tenements rending and sinking, until a deep chasm or ravine, B, was formed extending nearly three quarters of a mile in length, with a depth of from 100 to 150 feet, and a breadth exceeding 240 feet. At the bottom of this deep gulf lie fragments of the original surface thrown together in the wildest confusion. In consequence of lateral movements, the tract intervening between the new fissure and the sea, including the ancient undercliff, was fractured, and the whole line of sea-cliff carried bodily forwards for many yards. "A remarkable pyramidal crag, F, off Culverhole Point, which lately formed a distinguishing landmark, has sunk from a height of about seventy to twenty feet, and the main cliff, E, before more than fifty feet distant from this insulated crag, is now brought almost close to it. This motion of the sea-cliff has produced a further effect, which may rank among the most striking phenomena of this catastrophe. The lateral pressure of the descending rocks has urged the neighbouring strata, ex-

tending beneath the shingle of the shore, by their state of unnatural condensation to burst upwards in a line parallel to the coast, — thus an elevated ridge, G, more than a mile in length, and rising more than forty feet, covered by a confused assemblage of broken strata, and immense blocks of rock, invested with sea-weed and corallines, and scattered over with shells and star-fish, and other productions of the deep, forms an extended reef in front of the present range of cliffs." *

Cornwall. — Near Penzance in Cornwall, there is a projecting tongue of land, called the "Green," formed of granitic sand, from which more than thirty acres of pasture land have been gradually swept away in the course of the last two or three centuries. † It is also said that St. Michael's Mount, now an insular rock, was formerly situated in a wood, several miles from the sea; and its old Cornish name (Caraclowse in Cowse) signifies, according to Carew, the Hoare Rock in the Wood. ‡ Between the Mount and Newlyn there is seen under the sand black vegetable mould, full of hazel nuts, and the branches, leaves, roots, and trunks of forest trees, all of indigenous species. This stratum has been traced seaward as far as the ebb permits, and many proofs of a submerged vegetable accumulation, with stumps of trees in the position in which they grew, have been traced, says Mr. De la Beche, round the shores of Devon, Cornwall, and Western Somerset. The facts not only indicate a change in the relative level of the sea and land, since the species of animals and plants were the same as those now living in this

* Rev. W. D. Conybeare, letter dated Axminster, Dec. 31, 1839.

† Boase, Trans. Royal Geol. Soc. of Cornwall, vol. ii. p. 129.

‡ Ibid. p. 135.

district; but, what is very remarkable, there seems evidence of the submergence having been effected, in part at least, since the country was inhabited by man.*

A submarine forest occurring at the mouth of the Parret in Somersetshire, on the south side of the Bristol Channel, was described by Mr. L. Horner, in 1815, and its position attributed to subsidence. A bed of peat is there seen below the level of the sea, and the trunks of large trees, such as the oak and yew, having their roots still diverging as they grew, and fixed in blue clay.†

Tradition of loss of land in Cornwall.— The oldest historians mention a celebrated tradition in Cornwall, of the submersion of the Lionnesse, a country which formerly stretched from the Land's End to the Scilly Islands. The tract, if it existed, must have been thirty miles in length, and perhaps ten in breadth. The land now remaining on either side is from two hundred to three hundred feet high; the intervening sea about three hundred feet deep. Although there is no evidence for this romantic tale, it probably originated in some catastrophe occasioned by former inroads of the Atlantic, accompanying, perhaps, a subsidence of land on this coast.‡

West coast of England.— Having now brought together an ample body of proofs of the destructive operations of the waves, tides, and currents, on our eastern and southern shores, it will be unnecessary to enter into details of changes on the western coast, for they present merely a repetition of the same phenomena, and in general on an inferior scale. On the

* De la Beche's Report on the Geology of Devon, &c. chap. xiii.

† Geol. Trans., 1st series, vol. iii. p. 383.

‡ Boase, Trans. Royal Geol. Soc. of Cornwall, vol. ii. p. 130.

borders of the estuary of the Severn the flats of Somersetshire and Gloucestershire have received enormous accessions, while, on the other hand, the coast of Cheshire, between the rivers Mersey and Dee, has lost, since the year 1764, many hundred yards, and some affirm more than half a mile, by the advance of the sea upon the abrupt cliffs of red clay and marls. Within the period above mentioned several lighthouses have been successively abandoned.* There are traditions in Pembrokeshire† and Cardiganshire‡ of far greater losses of territory than that which the Lionnesse tale of Cornwall pretends to commemorate. They are all important, as demonstrating that the earliest inhabitants were familiar with the phenomenon of incursions of the sea.

Loss of land on the coast of France.— The French coast, particularly that of Brittany, where the tides rise to an extraordinary height, is the constant prey of the waves. In the ninth century many villages and woods are reported to have been carried away, the coast undergoing great change, whereby the hill of St. Michael was detached from the mainland. The parish of Bourgneuf, and several others in that neighbourhood, were overflowed in the year 1500. In 1735, during a great storm, the ruins of Palnel were seen uncovered in the sea.§

* Stevenson, Jameson's Ed. New Phil. Journ., No. 8. p. 386.

† Camden, who cites Gyraldus, also Ray, "On the Deluge," Phys. Theol. p. 228.

‡ Meyrick's Cardigan.

§ Von Hoff, Geschichte, &c. vol. i. p. 49.

CHAPTER VIII.

ACTION OF TIDES AND CURRENTS — *continued.*

Inroads of the sea upon the delta of the Rhine in Holland — Changes in the arms of the Rhine — Estuary of the Bies Bosch, formed in 1421 — Zuyder Zee, in the 13th century — Islands destroyed — Delta of the Ems converted into a Bay — Estuary of the Dollart formed — Encroachment of the sea on the coast of Sleswick — On shores of North America -- Tidal wave, called the Bore — Influence of tides and currents on the mean level of seas — Action of currents in inland lakes and seas — Baltic — Cimbrian deluge — Straits of Gibraltar — No under-current there — Whether salt is precipitated in the Mediterranean — Waste of shores of Mediterranean.

Inroads of the sea at the mouths of the Rhine.— The line of British coast considered in the preceding chapter offered no example of the conflict of two great antagonist forces; the influx, on the one hand, of a river draining a large continent, and on the other, the action of the waves, tides, and currents of the ocean. But when we pass over by the Straits of Dover to the Continent, and proceed north-eastwards, we find an admirable illustration of such a contest, where the ocean and the Rhine are opposed to each other, each disputing the ground now occupied by Holland; the one striving to shape out an estuary, the other to form a delta. There was evidently a period when the river obtained the ascendency, when the shape of the coast and set of the tides were probably very different; but

for the last two thousand years, during which man has witnessed and actively participated in the struggle, the result has been in favour of the ocean; the area of the whole territory having become more and more circumscribed; natural and artificial barriers having given way, one after another; and many hundred thousand human beings having perished in the waves.

Changes in the arms of the Rhine.—The Rhine, after flowing from the Grison Alps, copiously charged with sediment, first purifies itself in the Lake of Constance, where a large delta is formed; then, swelled by the Aar and numerous other tributaries, it flows for more than six hundred miles towards the north: when, entering a low tract, it divides into two arms, north of Cleves, a little below the village of Pannerden — a point which must therefore be considered the head of its delta. (See map, Pl. 5.) In speaking of the delta I do not mean to assume that all that part of Holland which is comprised within the several arms of the Rhine can be called a delta in the strictest sense of the term; because some portion of the country thus circumscribed, as, for example, a part of Gelderland and Utrecht, consists of strata which may have been deposited in the sea before the Rhine existed. These older tracts may either have been raised like the Ullah Bund in Cutch, during the period when the sediment of the Rhine was converting a part of the sea into land, or they may have constituted islands previously.

When the river divides north of Cleves, the left arm takes the name of the Waal; and the right, retaining that of the Rhine, is connected, a little farther to the north, by an artificial canal with the river Yssel. Still lower down, the Rhine takes the name of the Leck, a name which was given to distinguish it from another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arm called the old Rhine, which was sanded up until after the year 1825, when a channel was cut for it, by which it now enters the sea at Catwyck. It is common, in all great deltas, that the principal channels of discharge should shift from time to time; but in Holland so many magnificent canals have been constructed, and have so diverted, from time to time, the course of the waters, that the geographical changes in this delta are endless, and their history, since the Roman era, forms a complicated topic of antiquarian research. The present head of the delta is about forty geographical miles from the nearest part of the gulf called the Zuyder Zee, and more than twice that distance from the general coast-line. The present head of the delta of the Nile is about 80 or 90 geographical miles from the sea; that of the Ganges, as before stated, 220; and that of the Mississippi about 180, reckoning from the point where the Atchafalaya branches off, to the extremity of the new tongue of land in the Gulf of Mexico. But the comparative distance between the heads of deltas and the sea affords scarcely any data for estimating the relative magnitude of the alluvial tracts formed by their respective rivers. For the ramifications depend on many varying and temporary circumstances, and the area over which they extend does not hold any constant proportion to the volume of water in the river.

The Rhine therefore has at present three mouths. About two thirds of its waters flow to the sea by the Waal, and the remainder is carried partly to the Zuyder Zee by the Yssel, and partly to the ocean by the Leck. As the whole coast to the south, as far as Ostend, and on the north, to the entrance of the Baltic, has, with few exceptions, from time immemorial,

yielded to the force of the waves, it is evident that the common delta of the Rhine, Meuse, and Scheldt, for these three rivers may all be considered as discharging their waters into the same part of the sea, would, if its advance had not been checked, have become extremely prominent; and even if it had remained stationary, would long ere this have projected far beyond the rounded outline of the coast, like that strip of land already described, at the mouth of the Mississippi. But we find, on the contrary, that the islands which skirt the coast have not only lessened in size, but in number also, while great bays have been formed in the interior by incursions of the sea.

I have said that the coast to the south as far as Ostend has given away. This statement may at first seem opposed to the fact that the tract between Antwerp and Nieuport, marked *a, a* on the annexed map, (plate 5.), although now dry land, and supporting a large population, has, within the historical period, been covered with the sea. This region, however, consisted, in the time of the Romans, of woods, marshes, and peat mosses, protected from the ocean by a chain of sandy dunes, which were afterwards broken through during storms, especially in the fifth century. The waters of the sea during these irruptions threw down upon the barren peat a horizontal bed of fertile clay, which is in some places three yards thick, full of recent shells and works of art. The inhabitants, by the aid of embankments and the sand dunes of the coast, have succeeded, although not without frequent disasters, in defending the soil thus raised by the marine deposit.*

* Belpaire, Mém. de l'Acad. Roy. de Bruxelles, tom. x. 1837. Dumont, Bulletin of the same Soc. tom. v. p. 643.

Inroads of the Sea in Holland.—If we pass to the northward of the territory just alluded to, and cross the Scheldt, we find that between the fourteenth and eighteenth centuries parts of the islands Walcheren and Beveland were swept away, and several populous districts of Kadzand, losses which far more than counterbalance the gain of land caused by the sanding up of some pre-existing creeks. In 1658 the island Orisant was annihilated. One of the most memorable inroads of the sea occurred in 1421, when the tide, pouring into the mouth of the united Meuse and Waal, burst through a dam in the district between Dort and Gertrudenberg, and overflowed seventy-two villages, forming a large sheet of water called the Bies Bosch. Thirty-five of the villages were irretrievably lost, and no vestige, even of their ruins, was afterwards seen. The rest were redeemed, and the site of the others, though still very generally represented on maps as an estuary, has in fact been gradually filled up by alluvial deposits, and had become in 1835, as I was informed by Professor Moll, an immense plain, yielding abundant crops of hay, though still uninhabited. To the north of the Meuse is a long line of shore covered with sand dunes, where great encroachments have taken place from time to time, in consequence chiefly of the prevalence of south-easterly winds, which blow down the sands towards the sea. The church of Scheveningen, not far from the Hague, was once in the middle of the village, and now stands on the shore; half the place having been overwhelmed by the waves in 1570. Catwyck, once far from the sea, is now upon the shore; two of its streets having been overflowed, and land torn away to the extent of 200 yards in 1719. It is only by aid of embankments, that Petten, and several

other places farther north, have been defended against the sea.

Formation of the Zuyder Zee and Straits of Staveren. — Still more important are the changes which have taken place on the coast opposite the right arm of the Rhine, or the Yssel, where the ocean has burst through a large isthmus, and entered the inland lake Flevo, which, in ancient times, was, according to Pomponius Mela, formed by the overflowing of the Rhine over certain lowlands. It appears that, in the time of Tacitus, there were several lakes on the present site of the Zuyder Zee, between Friesland and Holland. The successive inroads by which these, and a great part of the adjoining territory, were transformed into a great gulf, began about the commencement, and were completed towards the close of the thirteenth century. Alting gives the following relation of the occurrence, drawn from manuscript documents of contemporary inhabitants of the neighbouring provinces. In the year 1205, the island now called Wieringen, to the south of the Texel, was still a part of the mainland, but during several high floods, of which the dates are given, ending in December, 1251, it was separated from the continent. By subsequent incursions, the sea consumed great parts of the rich and populous isthmus, a low tract which stretched on the north of Lake Flevo, between Staveren in Friesland and Medemblick in Holland, till at length a breach was completed about the year 1282, and afterwards widened. Great destruction of land took place when the sea first broke in, and many towns were swept away; but there was afterwards a reaction to a certain extent, large tracts at first submerged, having been gradually redeemed. The new straits south of Staveren are more than half the

width of those of Dover, but are very shallow, the greatest depth not exceeding two or three fathoms. The new bay is of a somewhat circular form, and between *thirty* and *forty* miles in diameter. How much of this space may formerly have been occupied by Lake Flevo is unknown. (See Map, Plate 5.)

Destruction of Islands. — A series of islands stretching from the Texel to the mouths of the Weser and Elbe, are evidently the last relics of a tract once continuous. They have greatly diminished in size, and have lost about a third of their number since the time of Pliny; for that naturalist counted twenty-three islands between the Texel and Eyder, whereas there are now only sixteen, including Heligoland and Neuwerk.* Heligoland, at the mouth of the Elbe, began in the year 800 to be much consumed by the waves. In the years 1300, 1500, and 1649, other parts were swept away, till at last a small portion only of the original island remained, consisting of a rock of red marl (of the keuper formation of the Germans), about 200 feet high. Since 1770, a current has cut a passage, navigable for large ships, through this remaining portion, and has formed two islands, Heligoland and Sandy Island.† On the other hand, some few islands have extended their bounds in one direction, or become connected with others, by the sanding-up of channels; but even these, like Juist, have generally given way as much on the north towards the sea as they have gained on the south, or land side.

The Dollart formed. — While the delta of the Rhine has suffered so materially from the movements of the ocean, it can hardly be supposed that minor rivers on

* Von. Hoff, vol. i. p. 364. † Id. p. 57.

the same coast should have been permitted to extend their deltas. It appears, that in the time of the Romans there was an alluvial plain of great fertility, where the Ems entered the sea by three arms. This low country stretched between Groningen and Friesland, and sent out a peninsula to the north-east towards Emden. A flood in 1277, first destroyed part of the peninsula. Other inundations followed at different periods throughout the fifteenth century. In 1507, a part only of Torum, a considerable town, remained standing; and in spite of the erection of dams, the remainder of that place, together with market-towns, villages, and monasteries, to the number of fifty, were finally overwhelmed. The new gulf, which was called the Dollart, although small in comparison to the Zuyder Zee, occupied no less than six square miles at first; but part of this space was, in the course of the two following centuries, again redeemed from the sea. The small bay of Leybucht, farther north, was formed in a similar manner in the thirteenth century; and the bay of Harlbucht in the middle of the sixteenth. Both of these have since been partially reconverted into dry land. Another new estuary, called the Gulf of Jahde, near the mouth of the Weser, scarcely inferior in size to the Dollart, has been gradually hollowed out since the year 1016, between which era and 1651 a space of about four square miles has been added to the sea. The rivulet which now enters this inlet is very small; but Arens conjectures, that an arm of the Weser had once an outlet in that direction.

Coast of Sleswick.—Farther north we find so many records of waste on the western coast of Sleswick, as to lead us to anticipate, that, at no distant period in the history of the physical geography of Europe,

Jutland may become an island, and the ocean may obtain a more direct entrance into the Baltic. Indeed, the temporary insulation of the northern extremity of Jutland has been effected no less than four times within the records of history, the ocean having as often made a breach through the bar of sand, which usually excludes it from the Lym Fiord. This long frith is 120 miles in length including its windings, and communicates at its eastern end with the Baltic. The last irruption of salt-water happened in 1824, and the fiord was still open in 1837, when some vessels of thirty tons burden passed through.

The Marsh islands between the rivers Elbe and Eyder are mere banks, like the lands formed of the "warp" in the Humber, protected by dikes. Some of them, after having been inhabited with security for more than ten centuries, have been suddenly overwhelmed. In this manner, in 1216, no less than ten thousand of the inhabitants of Eyderstede and Ditmarsch perished; and on the 11th of October, 1634, the islands and the whole coast, as far as Jutland, suffered by a dreadful deluge.

Destruction of Northstrand by the Sea.—Northstrand, up to the year 1240, was, with the islands Sylt and Föhr, so nearly connected with the mainland as to appear a peninsula, and was called North Friesland, a highly cultivated and populous district. It measured from nine to eleven geographical miles from north to south, and six to eight from east to west. In the above-mentioned year it was torn asunder from the continent, and in part overwhelmed. The isle of Northstrand, thus formed, was, towards the end of the sixteenth century, only four geographical miles in circumference, and was still celebrated for its cultivation

and numerous population. After many losses, it still contained nine thousand inhabitants. At last, in the year 1634, on the evening of the 11th of October, a flood passed over the whole island, whereby 1300 houses, with many churches, were lost; fifty thousand head of cattle perished, and above six thousand men. Three small islets, one of them still called Northstrand, alone remained, which are now continually wasting.

The redundancy of river water in the Baltic, especially during the melting of ice and snow in spring, causes in general an outward current through the channel called the Cattegat. But after a continuance of north-westerly gales, especially during the height of the spring tides, the Atlantic rises; and, pouring a flood of water into the Baltic, commits dreadful devastations on the isles of the Danish Archipelago. This current even acts, though with diminished force, as far eastward as the vicinity of Dantzic.* Accounts written during the last ten centuries attest the wearing down of promontories on the Danish coast, the deepening of gulfs, the severing of peninsulas from the mainland, and the waste of islands, while in several cases marsh land, defended for centuries by dikes, has at last been overflowed, and thousands of the inhabitants whelmed in the waves.

Thus the island Barsoe, on the coast of Sleswick, has lost, year after year, an acre at a time. (See map, plate 5.) The island Alsen suffers in like manner. The peninsula Zingst was converted into an island in 1625. There is a tradition that the isle of Rugen was originally torn by a storm from the mainland of Pomerania: and it is known, in later times, to have lost

* See examples in Von Hoff, vol. i. p. 73., who cites Pisansky.

ground, in the year 1625, when a tract of land was carried away. Some of these islands consist of ancient alluvial accumulations, containing blocks of granite, which are also spread over the neighbouring mainland.

Cimbrian Deluge. — As we have already seen that during the flood before mentioned 6000 men and 50,000 head of cattle perished on Northstrand on the western coast of Jutland, we are well prepared to find that this peninsula, the Cimbrica Chersonesus of the ancients, has from a remote period been the theatre of like catastrophes. Accordingly, Strabo records a story, although he treats it as an incredible fiction, that during a high tide, the ocean rose upon this coast so rapidly, that men on horseback were scarce able to escape.* Florus, alluding to the same tradition, says, "Cimbri, Theutoni, atque Tigurini, ab extremis Galliæ profugi, cùm terras eorum inundasset Oceanus, novas sedes toto orbe quærebant." † This event, commonly called the "Cimbrian Deluge," is supposed to have happened about three centuries before the Christian era, but it is not improbable that the principal catastrophe was preceded and followed by many devastations like those experienced in modern times on the islands and shores of Jutland; and such calamities may well be conceived to have forced on the migration of some maritime tribes.

Inroads of the sea on the eastern shores of North America.— After so many authentic details respecting the destruction of the coast in parts of Europe best known, it will be unnecessary to multiply examples of analogous changes in more distant regions of the world.

* Book vii. Cimbri. † Lib. iii. cap. 3.

It must not, however, be imagined that our own seas form any exception to the general rule. Thus, for example, if we pass over to the eastern coast of North America, where the tides rise to a great elevation, we find many facts attesting the incessant demolition of land. At Cape May, for example, on the north side of Delaware Bay, in the United States, the encroachment of the sea was shown by observations made consecutively for sixteen years, from 1804 to 1820, to average about nine feet a year;* and at Sullivan's Island, which lies on the north side of the entrance of the harbour of Charleston, in South Carolina, the sea carried away a quarter of a mile of land in three years, ending in 1786.†

Tidal wave called "the Bore."—Before concluding my remarks on the action of the tides, I must not omit to mention the wave called "the Bore," which is sometimes produced in a river where a large body of water is made to rise suddenly, in consequence of the contraction of the channel. This wave terminates abruptly on the inland side; because the quantity of water contained in it is so great, and its motion so rapid, that time is not allowed for the surface of the river to be immediately raised by means of transmitted pressure. A tide wave thus rendered abrupt has a close analogy, observes Mr. Whewell, to the waves which curl over and break on a shelving shore.‡

The Bore which enters the Severn, where the phenomenon is of almost daily occurrence, is sometimes nine feet high, and at spring tides rushes up the estuary with extraordinary rapidity. The same phe-

* New Monthly Mag. vol. vi. p. 69.

† Von Hoff, vol. i. p. 96.

‡ Phil. Trans. 1833, p. 204.

nomenon is frequently witnessed in the principal branches of the Ganges, and in the Megna. "In the Hoogly, or Calcutta river," says Rennell, "the Bore commences at Hoogly Point, the place where the river first contracts itself, and is perceptible above Hoogly Town; and so quick is its motion, that it hardly employs four hours in travelling from one to the other, though the distance is nearly seventy miles. At Calcutta it sometimes occasions an instantaneous rise of five feet; and both here, and in every other part of its track, the boats, on its approach, immediately quit the shore, and make for safety to the middle of the river. In the channels, between the islands in the mouth of the Megna, the height of the Bore is said to exceed twelve feet; and is so terrific in its appearance, and dangerous in its consequences, that no boat will venture to pass at spring tide."* These waves may sometimes cause inundations, undermine cliffs, and still more frequently sweep away trees and land animals from low shores, so that they may be carried down, and ultimately imbedded in fluviatile or submarine deposits.

CURRENTS IN INLAND LAKES AND SEAS.

In such large bodies of water as the North American lakes, the continuance of a strong wind in one direction often causes the elevation of the water, and its accumulation on the leeward side; and while the equilibrium is restoring itself, powerful currents are occasioned. In Ootober 1833, a strong current in Lake Erie, caused partly by the set of the waters

* Rennell, Phil. Trans. 1781.

towards the outlet of the lake, and partly by the prevailing wind, burst a passage through the extensive peninsula called Long Point, and soon excavated a channel more than nine feet deep and nine hundred feet wide. Its width and depth have since increased, and a new and costly pier has been erected; for it is hoped that this event will permanently improve the navigation of Lake Erie for steam-boats.* On the opposite, or southern coast of this lake, in front of the town of Cleveland, the degradation of the cliffs had been so rapid for several years preceding a survey made in 1837, as to threaten many towns with demolition.† In the Black Sea, also, although free from tides, we learn from Pallas that there is a sufficiently strong current to undermine the cliffs in many parts, and particularly in the Crimea.

Straits of Gibraltar.—That the level of the Mediterranean is from twenty to thirty feet lower than that of the Red Sea, at Suez, has been already stated.‡

It is well known that a powerful current sets constantly from the Atlantic into the Mediterranean, and its influence extends along the whole southern borders of that sea, and even to the shores of Asia Minor. Captain Smyth found, during his survey, that the central current ran constantly at the rate of from three to six miles an hour eastward into the Mediterranean, the body of water being three miles and a half wide. But there are also two lateral currents—one on the European, and one on the African side; each of them about two miles and a half broad,

* MS. of Capt. Bayfield, R. N.

† Silliman's Journ., vol. xxxiv. p. 349.

‡ See p. 31.

and flowing at about the same rate as the central stream. These lateral currents ebb and flow with the tide, setting alternately into the Mediterranean and into the Atlantic. The excess of water constantly flowing in is very great, and there is only one cause to which this can be attributed, the loss of water in the Mediterranean by evaporation. That the level of this sea should be considerably depressed by this cause is quite conceivable, since we know that the winds blowing from the shores of Africa are hot and dry; and hygrometrical experiments recently made in Malta and other places, show that the mean quantity of moisture in the air investing the Mediterranean, is equal only to one half of that in the atmosphere of England. The temperature also of the great inland sea is upon an average higher, by $3\frac{1}{2}°$ of Fahrenheit, than the eastern part of the Atlantic ocean in the same latitude, which must greatly promote its evaporation. The Black Sea being situated in a higher latitude, and being the receptacle of rivers flowing from the north, is much colder, and its expenditure far less; accordingly, it does not draw any supply from the Mediterranean, but, on the contrary, contributes to it by a current flowing outwards, for the most part of the year, through the Dardanelles. The discharge, however, at the Bosphorus is so small, when compared to the volume of water carried in by rivers, as to imply a great amount of evaporation even in the Black Sea.

Whether salt be precipitated in the Mediterranean.— It is, however, objected, that evaporation carries away only fresh water, and that the current from the Atlantic is continually bringing in salt water: why, then, do not the component parts of the waters of the Mediterranean vary? or how can they remain so nearly

the same as those of the ocean? Some have imagined that the excess of salt might be carried away by an under-current running in a contrary direction to the superior; and this hypothesis appeared to receive confirmation from a late discovery that the water taken up about fifty miles within the Straits, from a depth of 670 fathoms, contained a quantity of salt *four times greater* than the water of the surface. Dr. Wollaston,* who analysed this water obtained by Captain Smyth, truly inferred that an under-current of such denser water flowing outward, if of equal breadth and depth with the current near the surface, would carry out as much salt below as is brought in above, although it moved with less than one fourth part of the velocity, and would thus prevent a perpetual increase of saltness in the Mediterranean beyond that existing in the Atlantic. It was also remarked by others, that the result would be the same if, the swiftness being equal, the inferior current had only one fourth of the volume of the superior. At the same time there appeared reason to conclude that this great specific gravity was only acquired by water at immense depths; for two specimens of the water, taken within the Mediterranean, at the distance of some hundred miles from the Straits, and at depths of 400, and even 450 fathoms, were found by Dr. Wollaston not to exceed in density that of many ordinary samples of sea-water. Such being the case, we can now prove that the vast amount of salt brought into the Mediterranean, *does not* pass out again by the Straits; for it appears by Captain Smyth's soundings, which Dr. Wollaston had not seen, that between the capes of Trafalgar and Spartel, which

* Phil. Trans. 1829, part i. p. 29.

are twenty-two miles apart, and where the Straits are shallowest, the deepest part, which is on the side of Cape Spartel, is only 220 fathoms. It is therefore evident, that if water sinks in certain parts of the Mediterranean, in consequence of the increase of its specific gravity, to greater depths than 220 fathoms, it can never flow out again into the Atlantic, since it must be stopped by the submarine barrier which crosses the shallowest part of the Straits of Gibraltar.

The idea of the existence of a counter-current, at a certain depth, first originated in the following circumstance; — M. De l'Aigle, commander of a privateer called the Phœnix of Marseilles, gave chase to a Dutch merchant-ship, near Ceuta Point, and coming up with her in the middle of the gut between Tariffa and Tangier, gave her one broadside, which directly sunk her. A few days after, the sunken ship, with her cargo of brandy and oil, was cast ashore near Tangier, which is at least four leagues to the westward of the place where she went down, and to which she must have floated in a direction contrary to the course of the *central* current.* This fact, however, affords no evidence of an under current, because the ship, when it approached the coast, would necessarily be within the influence of a lateral current, which, running westward twice every twenty-four hours, might have brought back the vessel to Tangier.

What, then, becomes of the excess of salt? — for this is an inquiry of the highest geological interest. The Rhone, the Po, the Nile, and many hundred minor streams and springs, pour annually into the Mediterranean large quantities of carbonate of lime, together

* Phil. Trans. 1724.

with iron, magnesia, silica, alumina, sulphur, and other mineral ingredients, in a state of chemical solution. To explain why the influx of this matter does not alter the composition of this sea has never been regarded as a difficulty; for it is known that calcareous rocks are forming in the delta of the Rhone, in the Adriatic, on the coast of Asia Minor, and in other localities. Precipitation is acknowlegded to be the means whereby the surplus mineral matter is disposed of, after the consumption of a certain portion in the secretions of testacea, zoophytes, and other marine animals. But before muriate of soda can, in like manner, be precipitated, the whole Mediterranean ought, according to the received principles of chemistry, to become as much saturated with salt as Lake Aral, the Dead Sea, or the brine-springs of Cheshire.

It is undoubtedly true, in regard to small bodies of water, that every particle must be fully saturated with muriate of soda, before a single crystal of salt can be formed; such is probably the case in all natural salterns: such, for example, as those described by travellers as occurring on the western borders of the Black Sea, where extensive marshes are said to be covered by thin films of salt after a rapid evaporation of sea water. The salt *étangs* of the Rhone, where salt has sometimes been precipitated in considerable abundance, have been already mentioned. But if the era of the almost complete separation of the Mediterranean from the ocean be of no higher antiquity than the deposition of the newest tertiary strata found at the northern base of the Pyrenees, it is conceivable that this inland sea, especially if its depth be enormous, may have grown more and more saline ever since its actual basin was formed, and yet there may not have

been time, even at great depths, for the acquisition of saltness approaching that of the Dead Sea.

In regard to the depth of the Mediterranean, it appears that the narrowest part of the Straits of Gibraltar, where they are about nine miles broad, between the Isle of Tariffa and Alcanzar Point, the depth of water varies from 160 to 500 fathoms : but between Gibraltar and Ceuta, Captain Smyth sounded to the enormous depth of 950 fathoms; where he found a gravelly bottom, with fragments of broken shells. Saussure sounded to the depth of two thousand feet, within a few yards of the shore, at Nice; and M. Bérard has lately fathomed to the depth of more than six thousand feet in several places without reaching the bottom.*

The central abysses, therefore, of this sea are, in all likelihood, at least as deep as the Alps are high; and, as at the depth of seven hundred fathoms only, water has been found to contain a proportion of salt four times greater than at the surface, we may presume that the excess of salt may be much greater at the depth of two or three miles. After evaporation, the surface water becomes impregnated with a slight excess of salt, and its specific gravity being thus increased, it instantly falls to the bottom, while lighter water rises to the top, or flows in, laterally, being always supplied by rivers and the current from the Atlantic. The heavier fluid, when it arrives at the bottom, cannot stop if it can gain access to any lower part of the bed of the sea, not previously occupied by water of the same density.

How far this accumulation of brine can extend before the inferior strata of water will part with any of their

* Bull. de la Soc. Géol. de France.—Résumé, p. 72. 1832.

salt, and what difference in such a chemical process the immense pressure of the incumbent ocean might occasion, are questions which cannot be answered in the present state of science.

The Straits of Gibraltar are said to become gradually wider by the wearing down of the cliffs on each side at many points; and the current sets along the coast of Africa, so as to cause considerable inroads in various parts, particularly near Carthage. Near the Canopic mouth of the Nile, at Aboukir, the coast was greatly devastated in the year 1784, when a small island was nearly consumed. By a series of similar operations, the old site of the cities of Nicopolis, Taposiris, Parva, and Canopus, have become a sand-bank.*

* Clarke's Travels in Europe, Asia, and Africa, vol. iii. pp. 340. and 363. 4th edition.

CHAPTER IX.

REPRODUCTIVE EFFECTS OF TIDES AND CURRENTS.

Silting up of estuaries does not compensate the loss of land on the borders of the ocean — Bed of the German Ocean — Composition and extent of its sand-banks — Strata deposited by currents on the southern and eastern shores of the Mediterranean — Transportation by currents of the sediment of the Amazon, Orinoco, and Mississippi — Stratification.

FROM the facts enumerated in the last chapter, it appears that, on the borders of the ocean, currents and tides co-operating with the waves of the sea are most powerful instruments in the destruction and transportation of rocks; and as numerous tributaries discharge their alluvial burden into the channel of one great river, so we find that many rivers deliver their earthy contents to one marine current, to be borne by it to a distance, and deposited in some deep receptacle of the ocean. The current not only receives this tribute of sedimentary matter from streams draining the land, but acts also itself on the coast, as does a river on the cliffs which bound a valley. The course of currents on the British shores is ascertained to be as tortuous as that of ordinary rivers. Sometimes they run between sand-banks, which consist of matter thrown down at certain points where the velocity of the stream had been retarded; but it very frequently happens, that as in a river one bank is made of low alluvial gravel,

while the other is composed of some hard and lofty rock constantly undermined, so the current, in its bends, strikes here and there upon a coast, which then forms one bank, while a shoal under water forms the other. If the coast be composed of solid materials, it yields slowly; so also if it be of great height, for in that case a large quantity of matter must be removed before the sea can penetrate to any distance.

In inland seas, where the tides are insensible, or on those parts of the borders of the ocean where they are feeble, it is scarcely possible to prevent a harbour at a river's mouth from silting up; for a bar of sand or mud is formed at points where the velocity of the turbid river is checked by the sea, or where the river and a marine current neutralize each other's force. For the current, as we have seen, may, like the river, hold in suspension a large quantity of sediment, or, co-operating with the waves, may cause the progressive motion of a shingle beach in one direction. I have already alluded to the erection of piers and groins at certain places on our southern coast, to arrest the course of the shingle and sand (see p. 73.). The immediate effect of these temporary obstacles is to cause a great accumulation of pebbles on one side of the barrier, after which the beach still moves on round the end of the pier at a greater distance from the land. This system, however, is often attended with a serious evil, for during storms the waves throw suddenly into the harbour the vast heap of pebbles which have collected for years behind the groin or pier, as happened in the late gale (Jan. 1839) at Dover.

Estuaries, how formed.—The formation and keeping open of large estuaries are due to the *combined influence* of tidal currents and rivers; for when the tide rises, a

large body of water suddenly enters the mouth of the river, where, becoming confined within narrower bounds, while its momentum is not destroyed, it is urged on, and, having to pass through a contracted channel, rises and runs with increased velocity, just as a stream, when it reaches the arch of a bridge scarcely large enough to give passage to its waters, rushes with a steep fall through the arch. During the ascent of the tide, a body of fresh water, flowing down in an opposite direction from the higher country, is arrested in its course for several hours; and thus a large lake of brackish water is accumulated, which, when the sea ebbs, is let loose, as on the removal of an artificial sluice or dam. By the force of this retiring water, the alluvial sediment both of the river and of the sea is swept away, and transported to such a distance from the mouth of the estuary, that a small part only can return with the next tide.

It sometimes happens, that during a violent storm a large bar of sand is suddenly made to shift its position, so as to prevent the free influx of the tides, or efflux of river water. Thus about the year 1500 the sands at Bayonne were suddenly thrown across the mouth of the Adour. That river, flowing back upon itself, soon forced a passage to the northward, along the sandy plain of Capbreton, till at last it reached the sea at Boucau, at the distance of *seven leagues* from the point where it had formerly entered. It was not till the year 1579 that the celebrated architect Louis de Foix, undertook, at the desire of Henry III., to re-open the ancient channel, which he at last effected with great difficulty.*

* Nouvelle Chronique de la Ville de Bayonne, pp. 113. 139. 1827.

Tides in Estuaries.—In the estuary of the Thames at London, and in the Gironde, the tide rises only for five hours and ebbs seven, and in all estuaries the water requires a longer time to run down than up; so that the preponderating force is always in the direction which tends to keep open a deep and broad passage. But for reasons already explained, there is naturally a tendency in all estuaries to silt up partially, since eddies, and backwaters, and points where opposing streams meet, are very numerous, and constantly change their position.

Silting up of estuaries does not compensate for loss of coasts.—Many writers have declared that the gain on our eastern coast, since the earliest periods of history, has more than counterbalanced the loss; but they have been at no pains to calculate the amount of loss, and have often forgotten that, while the new acquisitions are manifest, there are rarely any natural monuments to attest the former existence of the land that has been carried away. They have also taken into their account those tracts artificially recovered, which are often of great agricultural importance, and may remain secure, perhaps, for thousands of years, but which are only a few feet above the mean level of the sea, and are therefore exposed to be overflowed again by a small proportion of the force required to remove cliffs of considerable height on our shores. If it were true that the area of land annually abandoned by the sea in estuaries were equal to that invaded by it, there would still be no compensation *in kind.*

It will seem, at first sight, somewhat paradoxical, but it is nevertheless true, that the greater number of estuaries, although peculiarly exposed to the invasion of the sea, are usually contracting in size, even where

the whole line of coast is giving way. But the fact is, that the inroads made by the ocean upon estuaries, although extremely great, are completed during periods of comparatively short duration; and in the intervals between these irruptions, the mouths of rivers, like other parts of the coast, usually enjoy a more or less perfect respite. All the estuaries, taken together, constitute but a small part of a great line of coast; it is, therefore, most probable, that if our observations extend to a few centuries only, we shall not see any, and very rarely all, of this small part exposed to the fury of the ocean. The coast of Holland, and Friesland, if studied for several consecutive centuries since the Roman era, would generally have led to the conclusion that the land was encroaching fast upon the sea, and that the aggrandisement within the estuaries far more than compensated the losses on the open coast. But when our retrospect embraces the whole period, an opposite inference is drawn: and we find that the Zuyder Zee, the Bies Bosch, Dollart, and Jahde, are modern gulfs and bays, and that these points have been the principal theatres of the retreat, instead of the advance, of the land. If we possessed records of the changes on our coast for several thousand years, they would probably present us with similar results; and although we have hitherto seen our estuaries, for the most part, become partially converted into dry land, and bold cliffs intervening between the mouths of rivers consumed by the sea, this has merely arisen from the accidental set of the currents and tides during a brief period.

The current which flows round from the north-west, and bears against the eastern coast of England, transports, as we have seen, materials of various kinds.

Aided by the winds and waves, it undermines and sweeps away the granite, gneiss, trap rocks, and sandstone of Shetland, and removes the gravel and loam of the cliffs of Holderness, Norfolk, and Suffolk, which are between fifty and two hundred feet in height, and which waste at the rate of from one to six yards annually. It also bears away, in co-operation with the Thames and the tides, the strata of London clay on the coast of Essex and Sheppey. The sea at the same time consumes the chalk with its flints for many miles continuously on the shores of Kent and Sussex — commits annual ravages on the fresh-water beds, capped by a thick covering of chalk-flint gravel, in Hampshire, and continually saps the foundations of the Portland limestone. It receives, besides, during the rainy months, large supplies of pebbles, sand, and mud, which numerous streams from the Grampians, Cheviots, and other chains, send down to the sea. To what regions, then, is all this matter consigned? It is not retained in mechanical suspension by the waters of the ocean, nor does it mix with them in a state of chemical solution, — it is deposited *somewhere*, yet certainly not in the immediate neighbourhood of our shores; for, in that case, there would soon be a cessation of the encroachment of the sea, and large tracts of low land, like Romney Marsh, would almost everywhere encircle our island.

As there is now a depth of water, exceeding thirty feet, in some spots where towns like Dunwich flourished but a few centuries ago, it is clear that the current not only carries far away the materials of the wasted cliffs, but removes also the ruins of many of the regular strata at the bottom of the sea.

So great is the quantity of matter held in suspension

by the tidal current on our shores, that the waters are in some places artificially introduced into certain lands below the level of the sea; and by repeating this operation, which is called " warping," for two or three years, considerable tracts have been raised, in the estuary of the Humber, to the height of about six feet. If a current, charged with such materials, meets with deep depressions in the bed of the ocean, it must often fill them up; just as a river, when it meets with a lake in its course, fills it gradually with sediment.

The only records which we at present possess of the gradual shallowing of seas are confined, as might be expected, to estuaries, havens, and certain channels of no great depth; and to some inland seas, as the Baltic, Adriatic, and Arabian Gulf. It is only of late years, that accurate surveys and soundings have afforded data of comparison in very deep seas, of which future geologists will avail themselves.

An extraordinary gain of land is described to have taken place at the head of the Red Sea, the Isthmus of Suez having doubled in breadth since the age of Herodotus. In his time, and down to that of Arrian, Heroopolis was on the coast; now it is as far distant from the Red Sea as from the Mediterranean.* Suez in 1541 received into its harbour the fleet of Solyman II.; but it is now changed into a sand-bank. The country called Tehama on the Arabian side of the gulf has increased from three to six miles since the Christian era. Inland from the present ports are the ruins of more ancient towns, which were once on the sea-shore, and bore the same names. It is said that

* Danville, Mém. sur l'Egypte, p. 108.—Von Hoff, vol. i. p. 390.

the blown sand from the deserts supplies some part of the materials of this new land, and that the rest is composed of shells and corals, of which the growth is very rapid.

Filling up of the German Ocean.—The German Ocean is deepest on the Norwegian side, where the soundings give 190 fathoms; but the mean depth of the whole basin may be stated at no more than thirty-one fathoms.* The bed of this sea is traversed by several enormous banks, one of which, occupying a central position, trends from the Frith of Forth, in a north-easterly direction, to a distance of 110 miles; others run from Denmark and Jutland upwards of 105 miles to the north-west; while the greatest of all, the Dogger Bank, extends for upwards of 354 miles from north to south. The whole superficies of these enormous shoals is equal to about one fifth of the whole area of the German Ocean, or to about one third of the whole extent of England and Scotland.† The average height of the banks measures, according to Mr. Stevenson, about seventy-eight feet; the upper portion of them consisting of fine and coarse siliceous sand, mixed with comminuted corals and shells.‡

It has been supposed by some writers, that these vast submarine hills are made up bodily of drift sand, and other loose materials, principally supplied from the waste of the English, Dutch, and other coasts. But the late survey of the North Sea, conducted by Captain Hewett, affords ground for suspecting that this opinion is very erroneous. If such immense mounds of sand and mud had been accumulated under

* Stevenson on the Bed of the German Ocean, or North Sea. — Ed. Phil. Journ. No. V. p. 44. 1820.

† Ibid. p. 47. ‡ Ibid.

the influence of currents, the same causes ought nearly to have reduced to a level the entire bottom of the German Ocean; instead of which some long narrow ravines are found to intersect the banks. One of these varies from seventeen to forty-four fathoms in depth, and has very precipitous sides: in one part, called the "Inner Silver Pits," it is fifty-five fathoms deep. The shallowest parts of the Dogger Bank were found to be forty-two feet under water, except in one place, where the wreck of a ship had caused a shoal; so that we may suppose the currents, which vary in their velocity from a mile to two miles and a half per hour, to have power to prevent the accumulation of drift matter in places of less depth. It seems, then, that the great banks above alluded to, and the ravines which intersect them, cannot be due to the tides and currents now existing in this sea. They may, however, have been caused in great part by the movements of the ocean at some former period, when the bed of this sea, and the surface of the land adjoining, assumed its actual configuration.

Strata deposited by currents.—It appears extraordinary, that in some tracts of the sea, adjoining the coast of England, where we know that currents are not only sweeping along rocky masses, thrown down, from time to time, from the high cliffs, but also occasionally scooping out channels in the regular strata, there should exist fragile shells and tender zoophytes in abundance, which live uninjured by these violent movements. The ocean, however, is in this respect a counterpart of the land; and as, on the continents, rivers may undermine their banks, uproot trees, and roll along sand and gravel, while their waters are inhabited by testacea and fish, and their alluvial plains are

adorned with rich vegetation and forests, so the sea may be traversed by rapid currents, and its bed may here and there suffer great local derangement, without any interruption of the general order and tranquillity.

One important character in the formations produced by currents, is, the immense extent over which they may be the means of diffusing homogeneous mixtures, for these are often co-extensive with a great line of coast, and, by comparison with their deposits, the deltas of rivers must shrink into insignificance. In the Mediterranean, the same current which is rapidly destroying many parts of the African coast, between the Straits of Gibraltar and the Nile, preys also upon the delta of the Nile, and drifts the sediment of that great river to the eastward. To this source may be attributed the rapid accretions of land on parts of the Syrian shores where rivers do not enter.

It is the opinion of M. Girard, one of the scientific men who accompanied Napoleon's expedition to Egypt, and who were employed on the survey of the ancient canal of Amron, communicating between the Nile and the Red Sea, that the Isthmus of Suez itself is merely a bar formed by the deposition of this current and of the Nile, and that the two seas were formerly united.* It is certain, as before stated, that the isthmus is daily gaining in width by the accession of fresh deposits on the shores of the Mediterranean.†

Distribution of the sediment of the Amazon by currents.— Among the greatest deposits now in progress, and of which the distribution is chiefly determined by currents, we may class those between the mouths of

* Description de l'Egypte, Mémoires, tom. i. p. 33.

† Quarterly Review, No. lxxxvi. p. 445.

the Amazon and the southern coast of North America. It has been before stated that a great current flows along the coast of Africa, from the south, which, when it reaches the head of the Gulf of Guinea, and is opposed by the waters brought to the same spot by the Guinea current, streams off in a westerly direction, and pursues its rapid course quite across the Atlantic to the continent of South America. Here one portion proceeds along the northern coast of Brazil to the Caribbean Sea and the Gulf of Mexico. Captain Sabine found that this current was running with the astonishing rapidity of four miles an hour where it crosses the stream of the Amazon, which river preserves part of its original impulse, and has its waters not wholly mingled with those of the ocean at the distance of three hundred miles from its mouth.* The sediment of the Amazon is thus constantly carried to the north-west as far as to the mouths of the Orinoco, and an immense tract of swamp is formed along the coast of Guiana, with a long range of muddy shoals bordering the marshes, and becoming converted into land.† The sediment of the Orinoco is partly detained, and settles near its mouth, causing the shores of Trinidad to extend rapidly, and is partly swept away into the Caribbean Sea by the Guinea current. According to Humboldt, much sediment is carried again out of the Caribbean Sea into the Gulf of Mexico. The rivers, also, which descend from the high platform of Mexico, between the mouths of the Norte and Tampico, when they arrive, swollen by tropical

* Experiments to determine the Figure of the Earth, &c. p. 445.

† Lochead's Observations on the Nat. Hist. of Guiana. Edin. Trans. vol. iv.

rains, at the edge of that platform, bear down an enormous quantity of rock and mud to the sea; but the current, setting across their mouths, prevents the growth of deltas, and preserves an almost uniform curve in that line of coast.* It must, therefore, exert a great transporting power, and it cannot fail to sweep away part of the matter which is discharged from the mouths of the Norte and the Mississippi.

Area over which strata may be formed by currents.—In regard to the distribution of sediment by currents, it may be observed, that the rate of subsidence of the finer mud carried down by every great river into the ocean, or of that caused by the rolling of the waves upon a shore, must be extremely slow; for the more minute the separate particles of mud, the slower will they sink to the bottom, and the sooner will they acquire what is called their terminal velocity. It is well known that a solid body, descending through a resisting medium, falls by the force of gravity, which is constant, but its motion is resisted by the medium more and more as its velocity increases, until the resistance becomes sufficient to counteract the further increase of velocity. For example, a leaden ball, one inch diameter, falling through air of density as at the earth's surface, will never acquire greater velocity than 260 feet per second, and, in water, its greatest velocity will be 8 feet 6 inches per second. If the diameter of the ball were $\frac{1}{100}$ of an inch, the terminal velocities in air would be 26 feet, and in water .86 of a foot per second.

Now, every chemist is familiar with the fact, that minute particles descend with extreme slowness

* This coast has been examined by Captain Vetch.—See also Bauza's chart of the Gulf of Mexico.

through water, the extent of their surface being very great in proportion to their weight, and the resistance of the fluid depending on the amount of surface. A precipitate of sulphate of baryta, for example, will sometimes require more than five or six hours to subside one inch; * while oxalate and phosphate of lime require nearly an hour to subside about an inch and a half and two inches respectively,† so exceedingly small are the particles of which these substances consist.

When we recollect that the depth of the ocean is supposed frequently to exceed three miles, and that currents run through different parts of that ocean at the rate of four miles an hour, and when at the same time we consider that some fine mud carried away from the mouths of rivers and from sea-beaches, where there is a heavy surf, as well as the impalpable powder showered down by volcanos, may subside at the rate of only an inch per hour, we shall be prepared to find examples of the transportation of sediment over areas of indefinite extent.

It is not uncommon for the emery powder used in polishing glass, to take more than an hour to sink one foot. Suppose mud, composed of particles twice as coarse, to fall at the rate of two feet per hour, and these to be discharged into that part of the Gulf Stream which preserves a mean velocity of three miles an hour for a distance of two thousand miles; in twenty-eight days these particles will be carried 2016 miles, and will have fallen only to a depth of 224 fathoms.

In this example, however, it is assumed that the

* On the authority of Mr. Faraday.

† On the authority of Mr. R. Phillips.

current retains its superficial velocity at the depth of 224 fathoms, for which we have as yet no data. Experiments should be made to ascertain the rate of currents at considerable distances from the surface, and the time taken by the finest sediment to settle in sea-water of a given depth, and then the geologist may determine the area over which homogeneous mixtures may be simultaneously distributed in certain seas.

Stratification.—In regard to the internal arrangement of formations deposited in the deep sea by currents far from the land, we may infer that in them, as in deltas, there is usually a division into strata; for, in both cases, the accumulations are successive, and, for the most part, interrupted. The waste of cliffs on the British coast is almost entirely confined to the winter months; so that running waters in the sea, like those on the land, are periodically charged with sediment, and again become pure.

CHAPTER X.

IGNEOUS CAUSES.

Changes of the inorganic world, *continued* — Igneous causes — Division of the subject — Distinct volcanic regions — Region of the Andes — System of volcanos extending from the Aleutian isles to the Molucca and Sunda islands — Polynesian archipelago — Volcanic region extending from Central Asia to the Azores — Former connection of the Caspian, Lake Aral, and Sea of Azof — Tradition of deluges on the shores of the Bosphorus, Hellespont, and Grecian isles — Periodical alternation of earthquakes in Syria and Southern Italy — Western limits of the European region — Earthquakes rarer and more feeble as we recede from the centres of volcanic action — Extinct volcanos not to be included in lines of active vents.

We have hitherto considered the changes wrought, since the times of history and tradition, by the continued action of aqueous causes on the earth's surface; and we have next to examine those resulting from igneous agency. As the rivers and springs on the land, and the tides and currents in the sea, have, with some slight modifications, been fixed and constant to certain localities from the earliest periods of which we have any records, so the volcano and the earthquake have, with few exceptions, continued, during the same lapse of time, to disturb the same regions. But as there are signs, on almost every part of our continent, of great power having been exerted by running water on the surface of the land, and by waves, tides, and

currents on cliffs bordering the sea, where, in modern times no rivers have excavated, and no waves or tidal currents undermined — so we find signs of volcanic vents and violent subterranean movements in places where the action of fire has long been dormant. We can explain why the intensity of the force of aqueous causes should be developed in succession in different districts. Currents, for example, tides, and the waves of the sea, cannot destroy coasts, shape out or silt up estuaries, break through isthmuses, and annihilate islands, form shoals in one place, and remove them from another, without the direction and position of their destroying and transporting power becoming transferred to new localities. Neither can the relative levels of the earth's crust, above and beneath the waters, vary from time to time, as they are admitted to have varied at former periods, and as it will be demonstrated that they still do, without the continents being, in the course of ages, modified, and even entirely altered, in their external configuration. Such events must clearly be accompanied by a complete change in the volume, velocity, and direction of the streams and land floods to which certain regions give passage. That we should find, therefore, cliffs where the sea once committed ravages, and from which it has now retired — estuaries where high tides once rose, but which are now dried up — valleys hollowed out by water, where no streams now flow, is no more than we should expect; — these and similar phenomena are the necessary consequences of physical causes now in operation; and, if there be no instability in the laws of nature, similar fluctuations must recur again and again in time to come.

But, however natural it may be that the force of

running water in numerous valleys, and of tides and currents in many tracts of the sea, should now be *spent*, it is by no means so easy to explain why the violence of the earthquake and the fire of the volcano should also have become locally extinct, at successive periods. We can look back to the time when the marine strata, whereon the great mass of Etna rests, had no existence; and that time is extremely modern in the earth's history. This alone affords ground for anticipating that the eruptions of Etna will one day cease.

> Nec quæ sulfureis ardet fornacibus Ætna
> Ignea semper erit, *neque enim fuit ignea semper*,
> (Ovid. *Metam.* lib. 15 — 340.)

are the memorable words which are put into the mouth of Pythagoras by the Roman poet, and they are followed by speculations as to the cause of volcanic vents shifting their positions. Whatever doubts the philosopher expresses as to the nature of these causes, it is assumed, as incontrovertible, that the points of eruption will hereafter vary, *because they have formerly done so.*

I have endeavoured to show, in former chapters, that this principle of reasoning has been too much set at naught by some modern schools of geology, which not only refuse to conclude that great revolutions in the earth's surface are now in progress, or that they will take place hereafter, *because* they have often been repeated in former ages, but even assume the improbability of such a conclusion, and throw the whole weight of proof on those by whom that doctrine is embraced.

Division of the subject — Volcanic action may be defined to be "the influence exerted by the heated interior of the earth on its external covering." If we adopt this definition, without connecting it, as Humboldt has done, with the theory of secular refrigeration, or the cooling down of an original heated and fluid nucleus, we may then class under a general head all the subterranean phenomena, whether of volcanos, or earthquakes, or those insensible movements of the land, by which, as will afterwards appear, large districts may be depressed or elevated, without convulsions. According to this view, I shall consider first, the volcano; secondly, the earthquake; thirdly, the rising or sinking of land in countries where there are no volcanos or earthquakes; fourthly, the probable *causes* of the changes which result from subterranean agency.

It is a very general opinion, that earthquakes and volcanos have a common origin; for both are confined to certain regions, although the subterranean movements are least violent in the immediate proximity of volcanic vents, especially where the discharge of aëriform fluids and melted rock is made constantly from the same crater. But as there are particular regions, to which both the points of eruption and the movements of great earthquakes are confined, I shall begin by tracing out the geographical boundaries of some of these, that the reader may be aware of the magnificent scale on which the agency of subterranean fire is now simultaneously developed. Over the whole of the vast tracts alluded to, active volcanic vents are distributed at intervals, and most commonly arranged in a linear direction. Throughout the intermediate spaces there is abundant evidence that the

subterranean fire is at work continuously, for the ground is convulsed from time to time by earthquakes; gaseous vapours, especially carbonic acid gas, are disengaged plentifully from the soil; springs often issue at a very high temperature, and their waters are usually impregnated with the same mineral matters as are discharged by volcanos during eruptions.

VOLCANIC REGIONS.

Region of the Andes.— Of these great regions, that of the Andes of South America is one of the best defined, extending from the southward of Chili to the northward of Quito, from about lat. 43° S. to about 2° N. of the equator. In this range, however, comprehending forty-five degrees of latitude, there is an alternation on a grand scale of districts of active with those of extinct volcanos, or which, if not spent, have at least been dormant for the last three centuries. How long an interval of rest may entitle us to consider a volcano as entirely extinct is not easily determined; but we know that in Ischia there intervened between two consecutive eruptions a pause of seventeen centuries; and the discovery of America is an event of far too recent a date to allow us even to conjecture whether different portions of the Andes, nearly the whole of which are subject to earthquakes, may not experience alternately a cessation and renewal of eruptions. For different sets of vents may reciprocally relieve each other in the office of affording an escape to the imprisoned gases and lava, and we shall afterwards see that such periodical alternations have actually been observed in countries with which we have been longer acquainted.

The first line of active vents which have been seen in eruption in the Andes extends from lat. 43° 28′ S., or, from Yantales, opposite the isle of Chiloe, to Coquimbo, in lat. 30° S.; to these thirteen degrees of eruptions succeed more than eight degrees of latitude in which no volcanic action has been traced. We then come to the volcanos of Bolivia and Peru, reaching six degrees from S. to N., or from lat. 21° S. to lat. 15° S. Between the Peruvian volcanos and those of Quito, another space intervenes of no less than fourteen degrees of latitude, said to be free from volcanic action so far as yet known. The volcanos of Quito then succeed, beginning about 100 geographical miles south of the equator, and continuing for about 130 miles north of the line, when there occurs another undisturbed interval of more than six degrees of latitude, after which we arrive at the volcanos of Guatemala or Central America, north of the Isthmus of Panama.* Having thus traced out the line from south to north, I shall first state, in regard to the numerous vents of Chili, that the volcanos of Yantales and Osorno were in eruption during the great earthquake of 1835 at the same moment that the land was shaken in Chiloe, and in some parts of the Chilian coast permanently upheaved; whilst at Juan Fernandez, at the distance of no less than 720 geographical miles from Yantales, an eruption took place beneath the sea. Some of the volcanos of Chili are of great height, as that of Antuco, in lat 37° 40′ S., the summit of which is at least 16,000 feet

* At the end of Von Buch's Description of the Canary Islands (Paris ed. 1836) will be found a valuable sketch of the position and characteristic phenomena of the principal volcanos of the globe, compiled with great care, and critical discrimination; a source of information of which I have largely availed myself.

above the sea. From the flanks of this volcano, at a great height, immense currents of lava have issued, one of which flowed in the year 1828. This event is said to be an exception to the general rule; few volcanos in the Andes, and none of those in Quito, having been seen in modern times to pour out lava, but having merely ejected vapour or scoriæ.

Both the basaltic (or augitic) lavas, and those of the felspathic class, occur in Chili and other parts of the Andes, but the volcanic rocks of the felspathic family are said by Von Buch to be generally not trachyte, but a rock which has been called andesite, or a mixture of augite and albite. The last mentioned mineral contains soda instead of the potash found in common felspar.

The volcano of Rancagua, lat. 34° 15′ S., is said to be always throwing out ashes and vapours like Stromboli, a proof of the permanently heated state of certain parts of the interior of the earth below. The volcano of Maypo, lat. 33° 53′ S., on a plain near the base of which pumice and obsidian are found, has a cone surrounded by enormous beds of gypsum and dolomite. Lower down, at the height of 9000 feet, are strata of limestone containing fossil shells, some of which are described as identical in species with those found in the Jura limestone of Swabia.*

A year rarely passes in Chili without some slight shocks of earthquakes, and in certain districts not a month. Those shocks which come from the side of the ocean are the most violent, and the same is said to be the case in Peru. The town of Copiapo has been laid waste by this terrible scourge in the years 1773,

* Von Buch, p. 471.

1796, and 1819, or in both cases after regular intervals of twenty-three years. There have, however, been other shocks in that country in the periods intervening between the dates above mentioned, although probably all less severe, at least on the exact site of Copiapo. The evidence against a regular recurrence of volcanic convulsions at stated periods is so strong as a general fact, that we must be on our guard against attaching too much importance to a few striking but probably accidental coincidences. Among these last might be adduced the case of Lima, violently shaken by an earthquake on the 17th of June, 1578, and again on the very same day, 1678; or the eruptions of Coseguina in the years 1709 and 1809, which are the only two recorded of that volcano previous to that of 1835.*

Of the permanent upheaval of land after earthquakes in Chili, I shall have occasion to speak in the next chapter, when it will also be seen that great shocks often coincide with eruptions, either submarine, or from the cones of the Andes, showing the identity of the force which elevates continents with that which causes volcanic outbursts.†

The space between Chili and Peru, in which no volcanic action has been observed, is 160 nautical leagues from south to north. It is, however, as Von Buch observes, that part of the Andes which is least known, being thinly peopled, and in some parts entirely desert. The volcanos of Peru rise from a lofty platform to vast heights above the level of the sea, from 17,000 to 20,000 feet. The lava which has issued

* Darwin's Geol. Trans., 2d series, vol. v. p. 612.

† Ibid. p. 606.

from Viejo, lat. 16° 55′ S., accompanied by pumice, is composed of a mixture of crystals of albitic felspar, hornblende, and mica, a rock which has been considered as one of the varieties of andesite. Some tremendous earthquakes which have visited Peru in modern times will be mentioned in a subsequent chapter.

In regard to the district before alluded to, between Peru and Quito, extending through fourteen degrees of latitude, which is said to be entirely destitute of active volcanos, our information is extremely defective. Secondary sandstones and limestones containing ammonites reach here to the highest crest of the chain; but this fact alone is by no means conclusive of the non-volcanic character of these mountains, for the same has been observed in Central Chili, at the height of 15,000 feet, in mountains where there are active vents. The volcanos of Quito, occurring between the second degree of south and the third degree of north latitude, rise to vast elevations above the sea, many of them being between 14,000 and 18,000 feet high. The Indians of Lican have a tradition that the mountain called L'Altar, or Capac Urcu, which means "the chief," was once the highest of those near the equator, being higher than Chimborazo; but in the reign of Ouainia Abomatha, before the discovery of America, a prodigious eruption took place, which lasted eight years, and broke it down. The fragments of trachyte, says M. Boussingault, which once formed the conical summit of this celebrated mountain, are at this day spread over the plain.* Cotopaxi is the most lofty of all the South American volcanos which have been in a state of activity in modern times, its height being

* Bull. de la Soc. Géol. tom. vi. p. 55.

18,858 feet; and its eruptions have been more frequent and destructive than those of any other mountain. It is a perfect cone, usually covered with an enormous bed of snow, which has, however, been sometimes melted suddenly during an eruption; as in January 1803, for example, when the snows were dissolved in one night.

Deluges are often caused in the Andes by the liquefaction of great masses of snow, and sometimes by the rending open, during earthquakes, of subterranean cavities filled with water. In these inundations, fine volcanic sand, loose stones, and other materials which the water meets with in its descent, are swept away, and a vast quantity of mud, called "moya," is thus formed and carried down into the lower regions. Mud derived from this source descended, in 1797, from the sides of Tunguragua in Quito, and filled valleys a thousand feet wide to the depth of six hundred feet, forming barriers by which rivers were dammed up, and lakes occasioned. In these currents and lakes of moya thousands of small fish are sometimes enveloped, which, according to Humboldt, have lived and multiplied in subterranean cavities. So great a quantity of these fish were ejected from the volcano of Imbaburu in 1691, that fevers, which prevailed at the period, were attributed to the effluvia arising from the putrid animal matter.

In Quito, many important revolutions in the physical features of the country are said to have resulted, within the memory of man, from the earthquakes by which it has been convulsed. M. Boussingault declares his belief, that if a full register had been kept of all the convulsions experienced here and in other populous districts of the Andes, it would be found that the

trembling of the earth, had been incessant. The frequency of the movement, he thinks, is not due to volcanic explosions, but to the continual falling in of masses of rock which have been fractured and upheaved in a solid form at a comparatively recent epoch; but a longer series of observations would be requisite to confirm this opinion. According to the same author, the height of several mountains of the Andes has diminished in modern times.*

The great crest or cordillera of the Andes lowers itself at the Isthmus of Panama to the height of about 1000 feet, and even at the lowest point of separation between the two seas to 600 feet. What some geographers regard as a continuation of that chain in Central America lies to the east of a series of volcanos, many of which are active in the provinces of Pasto, Popayan, and Guatemala. Coseguina, on the south side of the Gulf of Fonseca, was in eruption in January 1835, and some of its ashes fell at Truxillo, on the shores of the Gulf of Mexico. What is still more remarkable, on the same day, at Kingston in Jamaica, the same shower of ashes fell, having been carried by an upper counter current against the regular east wind which was then blowing. Kingston is about 700 miles distant from Coseguina, and these ashes must have been more than four days in the air, having travelled 170 miles a day. Eight leagues to the southward of the crater, the ashes covered the ground to the depth of three yards and a half, destroying the fine woods and dwellings. Thousands of cattle perished, their bodies being in many instances one mass of scorched flesh. Deer and other wild animals sought the towns

* Bull. de la Soc. Géol. de France, tom. vi. p. 56.

for protection; many birds and quadrupeds were found suffocated in the ashes, and the neighbouring streams were strewed with dead fish.* Such facts throw light on geological monuments, for in the ashes thrown out at remote periods from the spent volcanos of Auvergne, we find the bones and skeletons of extinct species of quadrupeds.

Mexico.— The great volcanic chain, after having thus pursued its course for several thousand miles from south to north, sends off a branch in a new direction in Mexico, in the parallel of the city of that name, and is prolonged in a great platform, between the eighteenth and twenty-second degrees of north latitude. This high table-land is said to owe its present form to the circumstance of an ancient system of valleys, in a chain of granitic mountains, having been filled up to the depth of many thousand feet with various volcanic products. Five active volcanos traverse Mexico from west to east — Tuxtla, Orizaba, Popocatepetl, Jurullo, and Colima. Jurullo, which is in the centre of the great platform, is no less than 120 miles from the nearest ocean — an important circumstance, as showing that the proximity of the sea is not a necessary condition, although certainly a very general characteristic, of the position of active volcanos. The extraordinary eruption of this mountain, in 1759, will be described in the sequel. If the line which connects these five vents be prolonged in a westerly direction, it cuts the volcanic group of islands called the Isles of Revillagigedo.

To the north of Mexico there are said to be three, or according to some five, volcanos in the peninsula of California; and a volcano is reported to have been in

* Caldcleugh, Phil. Trans. 1836, p. 27.

eruption on the N. W. coast of America, near the Columbia river, lat. 45° 37′ N.

West Indies.—To return to the Andes of Quito: Von Buch inclines to the belief, that if we were better acquainted with the region to the east of the Madalena, and with New Granada and the Caraccas, we might find the volcanic chain of the Andes to be connected with that of the West Indian, or Caribbee Islands.

Of these islands there are two parallel series, the one to the west, which are all volcanic, and which rise to the height of several thousand feet; the others to the east, for the most part composed of calcareous rocks, and very low. In the former, or volcanic series, are Granada, St. Vincent, St. Lucia, Martinique, Dominica, Guadaloupe, Montserrat, Nevis, and St. Eustace. In the calcareous chain are Tobago, Barbadoes, Mariegallante, Grandeterre, Desirade, Antigua, Barbuda, St. Bartholomew, and St. Martin. The most considerable eruptions in modern times have been those of St. Vincent. Great earthquakes have agitated St. Domingo, as will be seen in the seventeenth chapter.

I have before mentioned the violent earthquakes which in 1812 convulsed the valley of the Mississippi at New Madrid, for the space of 300 miles in length. This happened exactly at the same time as the great earthquake of Caraccas, so that it is possible that these two points are parts of one volcanic region. The island of Jamaica, with a tract of the contiguous sea, has often experienced tremendous shocks; and these are frequent along a line extending from Jamaica to St. Domingo, and Porto Rico.

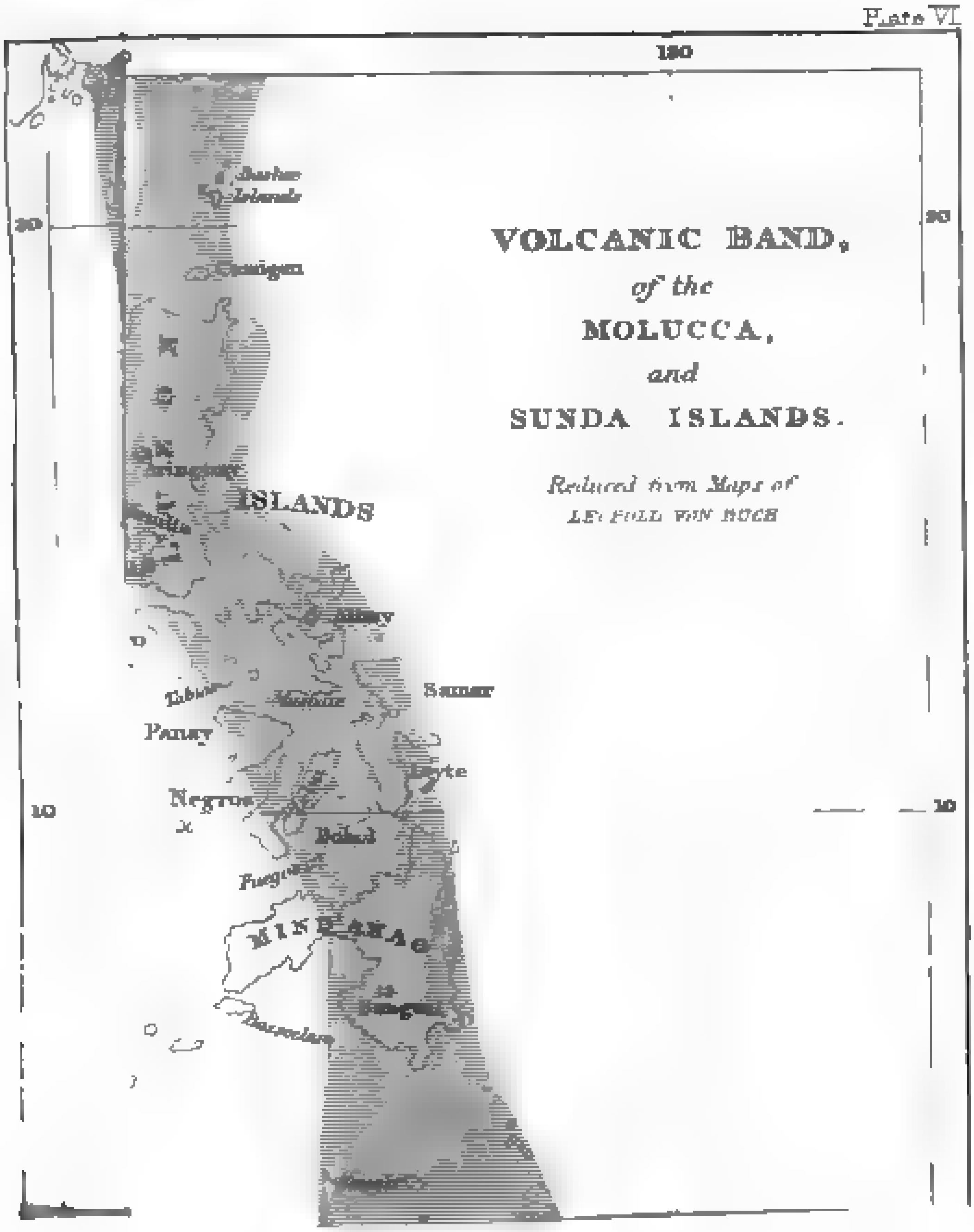
Thus it will be seen that, without taking account of the West Indian and Mexican branches, a linear train of volcanos and tracts shaken by earthquakes may be

traced from the island of Chiloe and opposite coast to Mexico, or even perhaps to the mouth of the Columbia river — a distance upon the whole as great as from the pole to the equator. In regard to the western limits of the region, they lie deep beneath the waves of the Pacific, and must continue unknown to us. On the east they are not prolonged, except where they include the West Indian Islands, to a great distance; for there seem to be no indications of volcanic disturbances in Buenos Ayres, Brazil, and the United States of North America.

Canada. — Although no volcanos have been discovered in the northern regions of the new continent, we have authentic accounts of frequent earthquakes in Canada, and some of considerable violence have occurred, as that of 1663, hereafter to be described. A large part of the estuary of the St. Lawrence and the surrounding country has been shaken from time to time; and we learn from Captain Bayfield's Memoirs, that along the shores of the estuary and gulf of St. Lawrence, horizontal banks of recent shells appear at various heights, from ten to one hundred feet above high-water mark, and inland beaches of sand and shingle with similar shells, as also elevated limestone rocks scooped out by the waves, and showing lines of lithodomous perforations, — facts which indicate most clearly the successive upheaving of the land since the sea was inhabited by the existing species of testacea.*

Volcanic region from the Aleutian Isles to the Moluccas and Isles of Sunda. — On a scale, which equals, or surpasses, that of the Andes, is another continuous line

* Proceedings of Geol. Soc. No. 33. p. 5., and Trans. of Lit. Soc. of Quebec, vols. i. ii.



† Von Buch, ibid. p. 409.

Soc. of Quebec, vols. i. ii.

of volcanic action, which commences, on the north, with the Aleutian Isles in Russian America, and extends, first in a westerly direction for nearly 200 geographical miles, and then southwards, without interruption, throughout a space of between sixty and seventy degrees of latitude to the Moluccas, where it sends off a branch to the south-east, while the principal train continues westerly through Sumbawa and Java to Sumatra, and then in a north-westerly direction to the Bay of Bengal.* This volcanic line, observes Von Buch, may be said to follow throughout its course the external border of the continent of Asia; while the branch which has been alluded to as striking south-east from the Moluccas, passes from New Guinea to New Zealand, conforming, though somewhat rudely, to the outline of Australia.† The northern extremity of this volcanic region is on the borders of Cook's Inlet, north-east of the Peninsula of Alaska, where one volcano, in about the sixtieth degree of latitude, is said to be 14,000 feet high. In Alaska itself are cones of vast height, which have been seen in eruption, and which are covered for two thirds of their height downwards with perpetual snow. The summit of the loftiest peak is truncated, having fallen in during an eruption in 1786.

From Alaska the line is continued through the Aleutian or Fox Islands to Kamtschatka. In the Aleutian Archipelago eruptions are frequent, and about thirty miles to the north of Unalaska, near the Isle of Umnack, a new island was formed in 1796. It was first observed after a storm, at a point in the sea from which a column of smoke had been seen to rise.

* See map of volcanic lines, which I have reduced and corrected from Von Buch's work on the Canaries.

† Von Buch, ibid. p. 409.

Flames then issued from the new islet which illuminated the country for ten miles round; a frightful earthquake shook the new-formed cone, and showers of stones were thrown as far as Umnack. The eruption continued for several months, and eight years afterwards, in 1804, when it was explored by some hunters, the soil was so hot in some places that they could not walk on it. According to Langsdorf and others, this new island, which is now several thousand feet high, and two or three miles in circumference, has been continually found to have increased in size when successively visited by different travellers; but we have no accurate means of determining how much of its growth, if any, has been due to upheaval, or how far it has been exclusively formed by the ejection of ashes and streams of lava. It seems, however, to be well attested that earthquakes of the most terrific description agitate and alter the bed of the sea and surface of the land throughout this tract.

The line is continued in the southern extremity of the Peninsula of Kamtschatka, where there are many active volcanos, which, in some eruptions, have scattered ashes to immense distances. The largest and most active of these is Klutschew, lat. 56° 3′ N. which rises at once from the sea to the prodigious height of 15,000 feet. Within 700 feet of the summit, Erman saw, in 1829, a current of lava, emitting a vivid light, flow down the north-west side to the foot of the cone. A flow of lava from the summit of Mont Blanc to its base in the valley of Chamouni would afford but an inadequate idea of the height from which this current descended. Large quantities of ice and snow opposed for a time a barrier to the lava, until at length the fiery torrent overcame, by its heat and pressure, this ob-

stacle, and poured down the mountain side with a frightful noise, which was heard for a distance of more than fifty miles.*

The Kurile chain of islands constitutes the prolongation of the range, where a train of volcanic mountains, nine of which are known to have been in eruption, trends in a southerly direction. In these, and in the bed of the adjoining sea, alterations of level have resulted from earthquakes since the middle of the last century. The line is then continued to the southwest in the great island of Jesso, where there are active volcanic vents, as also in Nipon, the principal of the Japanese group, where the number of burning mountains is very great; slight shocks of earthquakes being almost incessant, and violent ones experienced at distant intervals.

In Jedo, in 1783, an eruption of Alamo destroyed twenty-three villages by the showers of ashes and inundations of rivers which it caused. A great number of cones were thrown up on the same line, showing clearly that they followed one cleft in the mountain. Fusi, the loftiest mountain in Japan, a little south of Jedo, is nearly as high as the Peak of Teneriffe (12,000 feet), covered with perpetual snow, emitting vapours, and formerly flames. The falling in of part of this mountain is said to have happened before the Christian era; and so late as 1793, Unsen, another volcano farther to the south, fell in and caused a deep hollow, from which dense vapours issued, and an eruption and earthquakes followed, in which 53,000 persons perished.†

Between the Japanese and Phillippine Islands, the

* Von Buch, Descrip. des Iles Canar. p. 450., who cites Erman and others.

† Ibid. p. 440.

communication is preserved by several small insular vents. Sulphur Island, in the Loo Choo Archipelago, emits sulphureous vapour; and Formosa suffers greatly from earthquakes. In Luzon, the most northern and largest of the Phillippines, are three active volcanos; Sanguil, a volcano in Mindinao, was also in eruption in 1764. The line is then prolonged through Sangir and the north-eastern extremity of Celebes, by Ternate and Tidore, to the Moluccas. The chain of volcanos then sends off a branch by New Guinea, in a south-easterly direction towards New-Zealand, while, as before stated, another branch bends round to the west, and is prolonged through Sumbawa to the Sunda Islands. I shall first pursue the western branch. We have records of several streams of lava which have issued from the principal mountain in Banda; and it is stated that, in 1820, after an eruption, a solid mass, composed of large blocks of basalt, was raised out of the sea and filled up a great bay on the eastern side of the island, which had previously a depth of sixty fathoms. The mass rose so as to form hills, yet was not in a state of fusion, superficially at least, but disengaged vapours from fissures without the ejection of pumice or scoriæ. Von Buch infers from Reinwardt's Narrative, that, in this instance, beds of volcanic matter were up-raised into a dome-shaped form.* The great eruption of Tomboro in Sumbawa, in 1815, will be mentioned in the fifteenth chapter.

There are said to be thirty-eight considerable volcanos in Java, some of which are more than 10,000 feet high. They are remarkable for the quantity of sulphur and sulphureous vapours which they discharge.

* Von Buch, Descrip. des Iles Canar. p. 413.

They rarely emit lava, but rivers of mud issue from them, like the moya of the Andes of Quito. The memorable eruption of Galongoon, in 1822, will be described in the thirteenth chapter. The crater of Taschem, at the eastern extremity of Java, contains a lake of sulphuric acid, a quarter of a mile long, from which a river of acid water issues, which supports no living creature, nor can fish live in the sea near its confluence. There is an extinct crater near Batur, called Guevo Upas, or the Valley of Poison, about half a mile in circumference, which is justly an object of terror to the inhabitants of the country. Every living being which penetrates into this valley falls down dead, and the soil is covered with the carcasses of tigers, deer, birds, and even the bones of men; all killed by the abundant emanations of carbonic acid gas, by which the bottom of the valley is filled.

In another crater in this land of wonders, near the volcano of Talaga Bodas, we learn from Mr. Reinwardt, that the sulphureous exhalations have killed tigers, birds, and innumerable insects; and the soft parts of these animals, such as the fibres, muscles, nails, hair, and skin, are very well preserved, while the bones are corroded and entirely destroyed.

The same linear arrangement which is observed in Java holds good in the volcanos of Sumatra, some of which are of great height, as Berapi, which is more than 12,000 feet above the sea, and is continually smoking. Hot springs are abundant at its base. The volcanic line then inclines slightly to the north-west, and points to Barren Island, lat. 12° 15′ N., in the Bay of Bengal. This volcano was in eruption in 1792, and will be described in the fourteenth chapter. The volcanic train then extends, according to Dr. Macclelland,

to the island of Narcondam, lat. 13° 22′ N., which is a cone seven or eight hundred feet high, rising from deep water, and said to present signs of lava currents descending from the crater to the base. Afterwards the train stretches in the same direction to the volcanic island of Rambree, about lat. 19° N., and the adjoining island of Cheduba, which is represented in old charts as a burning mountain. Thus we arrive at the Chittagong coast, which in 1762 was convulsed by a tremendous earthquake (see chap. xvii.).*

To return now to the branch before mentioned as striking off from the Moluccas in a south-easterly direction, we find the volcanic band at first prolonged through part of New Guinea, and then continued by Admiralty Islands, New Britain, and Saloman's Islands to New Zealand. On the east of New Britain is a volcano, from which Dampier saw, in 1700, a current of incandescent lava flow down to the sea. In New Zealand, in lat. 37° S., an active volcano, called White Island, has lately been discovered.

To enumerate all the volcanic regions of the Indian and Pacific oceans would lead me far beyond the proper limits of this treatise, but it will appear in the last chapter of the third volume, when coral reefs are treated of, that the islands of the Pacific consist alternately of linear groups of two classes, the one lofty, and containing active volcanos, and marine strata above the sea-level, and which have been undergoing upheaval in modern times; the other very low, consisting of reefs of coral, usually with lagoons in their centres, and in which there is evidence of a gradual subsidence of the ground.

* Macclelland's Report on Coal and Min. Resources of India. Calcutta, 1838.

Volcanic region from Central Asia to the Azores.— Another great region of subterranean disturbance is that which extends through a large part of Central Asia to the Azores, or from China and Tartary through Lake Aral and the Caspian to the Caucasus, and the countries bordering the Black Sea, then again through part of Asia Minor to Syria, and westward to the Grecian islands, Greece, Naples, Sicily, the southern part of Spain, Portugal, and the Azores. Respecting the eastern extremity of this line in China, we have but little information, although many violent earthquakes are known to have occurred in that country. The volcano said to have been in eruption in the seventh century in Central Tartary is situated on the northern declivity of the Celestial Mountains, not far distant from the large lake called Issikoul, and Humboldt mentions other vents and solfataras in the same quarter, which are all worthy of notice, as being far more distant from the ocean (260 geographical miles) than any other known points of eruption.

We find on the western shores of the Caspian, in the country round Baku, a tract called the Field of Fire, which continually emits inflammable gas, while springs of naphtha and petroleum occur in the same vicinity, as also mud volcanos. In the chain of Elburs, to the south of this sea, is a lofty mountain, which, according to Morier, sometimes emits smoke, and at the base of which are several small craters, where sulphur and saltpetre are procured in sufficient abundance to be used in commerce. Violent subterranean commotions have been experienced along the borders of the Caspian; and, according to Engelhardt and Parrot, the bottom of that sea has, in modern times, varied in form; and, according to them, near the south

coast, the Isle of Idak, north from Astrabat, formerly high land, has now become very low.*

The steppes of the Caspian, or plains covered with recent shells, and terminated by shingle beaches and lines of inland cliffs, point to former alterations in the relative level of land and sea; and Pallas has endeavoured to show that an ancient strait, by which the Caspian was once united to the Sea of Azof, is still indicated by a low tract of sand.

In the country between the Caspian and the Black seas, and in the chain of Caucasus, numerous earthquakes have, in modern times, caused fissures and subsidences of the soil, especially at Tiflis.† The Caucasian territories abound in hot-springs and mineral waters. So late as 1814, a new island was raised by volcanic explosions in the Sea of Azof; and Pallas mentions that, in the same locality, opposite old Temruk, a submarine eruption took place in 1799, accompanied with dreadful thundering, emission of fire and smoke, and the throwing up of mire and stones. Violent earthquakes were felt at the same time at great distances from Temruk. The country around Erzerum exhibits similar phenomena.

Syria and Palestine abound in volcanic appearances, and very extensive areas have been shaken, at different periods, with great destruction of cities and loss of lives. Continual mention is made in history of the ravages committed by earthquakes in Sidon, Tyre, Berytus, Laodicea, and Antioch, and in the Island of Cyprus. The country around the Dead Sea appears evidently, from the accounts of modern travellers, to

* Travels in the Crimea and Caucasus, in 1815, vol. i. pp. 257. 264.—Von Hoff, vol. i. p. 137.

† Von Hoff, vol. ii. p. 210.

be volcanic. A district near Smyrna, in Asia Minor, was termed by the Greeks Catacecaumene, or the burnt, where there is a large arid territory, without trees, and with a cindery soil.*

Grecian Archipelago.— Proceeding westwards, we reach the Grecian Archipelago, where Santorin, afterwards to be described, is the grand centre of volcanic action. To the north-west of Santorin is another volcano in the Island of Milo, of recent aspect, having a very active solfatara in its central crater, and many sources of boiling water and steam. Continuing the same line, we arrive at that part of the Morea where we learn, from ancient writers, that Helice and Bura were, in the year 373 B. C., submerged beneath the sea by an earthquake; and the walls, according to Ovid, were to be seen beneath the waters. Near the same spot, in our times (1817,) Vostizza was laid in ruins by a subterranean convulsion.† At Methone, also (now Modon), in Messenia, about three centuries before our era, an eruption threw up a great volcanic mountain, which is represented by Strabo as being nearly 4000 feet in height; but the magnitude of the hill requires confirmation. Some suppose that the accounts of the formation of a hill near Trœzene, of which the date is unknown, may refer to the same event.

It was Von Buch's opinion that the volcanos of Greece were arranged in a line running N.N.W. and S.S.E., as represented in the map, Pl. 6.; and that they afforded the only example in Europe of active volcanos having a linear direction; ‡ but M. Virlet, on the contrary, announces as the result of his investi-

* Strabo, ed. Fal., p. 900.

‡ Von Hoff, vol. ii. p. 172.

‡ See plate of volcanic bands, p. 130.

igations, made during the late French expedition to the Morea, that there is no one determinate line of direction for the volcanic phenomena in Greece, whether we follow the points of eruptions, or the earthquakes, or any other signs of igneous agency.*

Macedonia, Thrace, and Epirus, have always been subject to earthquakes, and the Ionian Isles are continually convulsed.

Traditions of Deluges.— The traditions which have come down to us from remote ages of great inundations said to have happened in Greece and on the confines of the Grecian settlements, had doubtless their origin in a series of local catastrophes, caused principally by earthquakes. The frequent migrations of the earlier inhabitants, and the total want of written annals long after the first settlement of each country, make it impossible for us at this distance of time to fix either the true localities or probable dates of these events. The first philosophical writers of Greece were, therefore, as much at a loss as ourselves to offer a reasonable conjecture on these points, or to decide how many catastrophes might sometimes have become confounded in one tale, or how much this tale may have been amplified, in after times, or obscured by mythological fiction. The floods of Ogyges and Deucalion are commonly said to have happened before the Trojan war; that of Ogyges more than seventeen, and that of Deucalion more than fifteen centuries before Christ. As to the Ogygian flood, it is generally described as having laid waste Attica, and was referred by some writers to a great overflowing of rivers, to which cause Aristotle also attributed the deluge of Deucalion, which, he says,

* Virlet, Bulletin de la Soc. Géol. de France, tom. iii. p. 109.

affected Hellas only, or the central part of Thessaly. Others imagined the same event to have been due to an earthquake, which threw down masses of rock, and stopped up the course of the Peneus in the narrow defile between mounts Ossa and Olympus.

As to the deluge of Samothrace, which is generally referred to a distinct date, it appears that the shores of that small island and the adjoining mainland of Asia were inundated by the sea. Diodorus Siculus says that the inhabitants had time to take refuge in the mountains, and save themselves by flight; he also relates, that long after the event, the fishermen of the island drew up in their nets the capitals of columns, "which were the remains of cities submerged by that terrible catastrophe."* These statements scarcely leave any doubt that there occurred, at the period alluded to, a subsidence of the coast, accompanied by earthquakes and inroads of the sea. It is not impossible that the story of the bursting of the Black Sea through the Thracian Bosphorus into the Grecian Archipelago, which accompanied, and, as some say, caused the Samothracian deluge, may have reference to a wave, or succession of waves, raised in the Euxine by the same convulsion.

We know that subterranean movements and volcanic eruptions are often attended not only by incursions of the sea, but also by violent rains, and the complete derangement of the river drainage of the inland country, and by the damming up of the outlets of lakes by landslips, or obstructions in the courses of subterranean rivers, such as abound in Thessaly and the Morea. We need not therefore be surprised at the

* Book v. ch. xlvi. — See Letter of M. Virlet Bulletin de la Soc. Géol. de France, tom. ii. p. 341.

variety of causes assigned for the traditional floods of Greece, by Herodotus, Aristotle, Diodorus, Strabo, and others. As to the area embraced, had all the Grecian deluges occurred simultaneously, instead of being spread over many centuries, and had they, instead of being extremely local, reached at once from the Euxine to the south-western limit of the Peloponnese, and from Macedonia to Rhodes, the devastation would still have been more limited than that which visited Chili in 1835, when a volcanic eruption broke out in the Andes, opposite Chiloe, and another at Juan Fernandez, distant 720 geographical miles, at the same time that several lofty cones in the Cordillera, 400 miles to the eastward of that island, threw out vapour and ignited matter. Throughout a great part of the space thus recently shaken in South America, cities were laid in ruins, or the land was permanently upheaved, or mountainous waves rolled inland from the Pacific.

Respecting Southern Italy, Sicily, and the Lipari Isles, it is unnecessary to enlarge here, as I shall have occasion again to allude to them. I may mention, however, that a band of volcanic action has been traced by Dr. Daubeny across the Italian Peninsula, from Ischia to Mount Vultur, in Apulia, the commencement of the line being found in the hot springs of Ischia, after which it is prolonged through Vesuvius to the Lago d'Ansanto, where gases similar to those of Vesuvius are evolved. Its farther extension strikes Mount Vultur, a lofty cone composed of tuff and lava, from one side of which carbonic acid and sulphuretted hydrogen are emitted.*

* Daubeny on Mount Vultur, Ashmolean Memoirs. Oxford, 1835.

Periodical alternation of Earthquakes in Syria and Southern Italy.— It has been remarked by Von Hoff, that from the commencement of the thirteenth to the latter half of the seventeenth century, there was an almost entire cessation of earthquakes in Syria and Judea; and, during this interval of quiescence, the Archipelago, together with part of the adjacent coast of Lesser Asia, as also Southern Italy and Sicily, suffered greatly from earthquakes; while volcanic eruptions were unusually frequent in the same regions. A more extended comparison, also, of the history of the subterranean convulsions of these tracts seems to confirm the opinion, that a violent crisis of commotion never visits both at the same time. It is impossible for us to declare, as yet, whether this phenomenon is constant in this and other regions, because we can rarely trace back a connected seties of events farther than a few centuries; but it is well known that, where numerous vents are clustered together within a small area, as in many archipelagos for instance, two of them are never in violent eruption at once. If the action of one become very great for a century or more, the others assume the appearance of spent volcanos. It is, therefore, not improbable that separate provinces of the same great range of volcanic fires may hold a relation to one deep-seated focus, analogous to that which the apertures of a small group bear to some more superficial rent or cavity. Thus, for example, we may conjecture that, at a comparatively small distance from the surface, Ischia and Vesuvius mutually communicate with certain fissures, and that each affords relief alternately to elastic fluids and lava there generated. So we may suppose Southern Italy and Syria to be connected, at a much greater depth, with a lower part of the very same system

of fissures; in which case any obstruction occurring in one duct may have the effect of causing almost all the vapour and melted matter to be forced up the other, and if they cannot get vent, they may be the cause of violent earthquakes.

The north-eastern portion of Africa, including Egypt, which lies six or seven degrees south of the volcanic line already traced, has been almost always exempt from earthquakes: but the north-western portion, especially Fez and Morocco, which fall within the line, suffer greatly from time to time. The southern part of Spain also, and Portugal have generally been exposed to the same scourge simultaneously with Northern Africa. The provinces of Malaga, Murcia, and Granada, and in Portugal the country round Lisbon, are recorded at several periods to have been devastated by great earthquakes. It will be seen, from Michell's account of the great Lisbon shock in 1755, that the first movement proceeded from the bed of the ocean ten or fifteen leagues from the coast. So late as February 2, 1816, when Lisbon was vehemently shaken, two ships felt a shock in the ocean west from Lisbon; one of them at the distance of 120, and the other 262 French leagues from the coast *— a fact which is the more interesting, because a line drawn through the Grecian Archipelago, the volcanic region of Southern Italy, Sicily, Southern Spain, and Portugal, will, if prolonged westward through the ocean, strike the volcanic group of the Azores, which has therefore, in all probability, a submarine connection with the European line. How far the island of Ma-

* Verneur, Journal des Voyages, tom. iv. p. 111. — Von Hoff, vol. ii. p. 275.

deira, which has been subject to violent earthquakes, and the Canary Islands, in which volcanic eruptions have been frequent, may communicate beneath the waters with the same great region, must for the present be mere matter of conjecture.

In regard to the volcanic system of Southern Europe, it may be observed, that there is a central tract where the greatest earthquakes prevail, in which rocks are shattered, mountains rent, the surface elevated or depressed, and cities laid in ruins. On each side of this line of greatest commotion there are parallel bands of country, where the shocks are less violent. At a still greater distance (as in Northern Italy, for example, extending to the foot of the Alps), there are spaces where the shocks are much rarer and more feeble, yet possibly of sufficient force to cause, by continued repetition, some appreciable alteration in the external form of the earth's crust. Beyond these limits, again, all countries are liable to slight tremors at distant intervals of time, when some great crisis of subterranean movement agitates an adjoining volcanic region; but these may be considered as mere vibrations, propagated mechanically through the external covering of the globe, as sounds travel almost to indefinite distances through the air. Shocks of this kind have been felt in England, Scotland, Northern France, and Germany — particularly during the Lisbon earthquake. But these countries cannot, on this account, be supposed to constitute parts of the southern volcanic region, any more than the Shetland and Orkney islands can be considered as belonging to the Icelandic circle, because the sands ejected from Hecla have been wafted thither by the winds.

Besides the continuous spaces of subterranean disturbance, of which we have merely sketched the outline, there are other disconnected volcanic groups, of which several will be mentioned hereafter.

Lines of active and extinct Volcanos not to be confounded. — We must always be careful to distinguish between lines of extinct and active volcanos, even where they appear to run in the same direction; for ancient and modern systems may interfere with each other. Already, indeed, we have proof that this is the case; so that it is not by geographical position, but by reference to the species of organic beings alone, whether aquatic or terrestrial, whose remains occur in beds interstratified with lavas, that we can clearly distinguish the relative age of volcanos of which no eruptions are recorded. Had Southern Italy been known to civilized nations for as short a period as America, we should have had no record of eruptions in Ischia; yet we might have assured ourselves that the lavas of that isle had flowed since the Mediterranean was inhabited by the species of testacea now living in the Neapolitan seas. With this assurance, it would not have been rash to include the numerous vents of that island in the modern volcanic group of Campania.

On similar grounds we may infer, without much hesitation, that the eruptions of Etna, and the modern earthquakes of Calabria, are a continuation of that action which, at a somewhat earlier period, produced the submarine lavas of the Val di Noto in Sicily. But, on the other hand, the lavas of the Euganean hills and the Vicentin, although not wholly beyond the range of earthquakes in Northern Italy, must not be

confounded with any existing volcanic system; for when they flowed, the seas were inhabited by animals almost all of them distinct from those now known to live, whether in the Mediterranean or other parts of the globe.

CHAPTER XI.

VOLCANIC DISTRICT OF NAPLES.

History of the volcanic eruptions in the district round Naples — Early convulsions in the island of Ischia — Numerous cones thrown up there — Epomeo not an habitual volcano — Lake Avernus — The Solfatara — Renewal of the eruptions of Vesuvius, A. D. 79 — Pliny's description of the phenomena — Remarks on his silence respecting the destruction of Herculaneum and Pompeii — Subsequent history of Vesuvius — Lava discharged in Ischia in 1302 — Pause in the eruptions of Vesuvius — Monte Nuovo thrown up — Uniformity of the volcanic operations of Vesuvius and the Phlegræan Fields in ancient and modern times.

I SHALL next give a sketch of the history of some of the volcanic vents dispersed throughout the great regions before described, and consider the composition and arrangement of their lavas and ejected matter. The only volcanic region known to the ancients was that of the Mediterranean; and even of this they have transmitted to us very imperfect records relating to the eruptions of the three principal districts, namely, that round Naples, that of Sicily and its isles, and that of the Grecian Archipelago. By far the most connected series of records throughout a long period relates to the first of these provinces; and these cannot be too attentively considered, as much historical information is indispensable in order to enable us to obtain a clear

view of the connection and alternate mode of action of the different vents in a single volcanic group.

Early convulsions in the Island of Ischia. — The Neapolitan volcanos extend from Vesuvius, through the Phlegræan Fields, to Procida and Ischia, in a somewhat linear arrangement, ranging from the north-east to the south-west, as will be seen in the annexed map of the volcanic district of Naples (plate 7.). Within the space above limited, the volcanic force is sometimes developed in single eruptions from a considerable number of irregularly scattered points; but a great part of its action has been confined to one principal and habitual vent, Vesuvius or Somma. Before the Christian era, from the remotest periods of which we have any tradition, this principal vent was in a state of inactivity. But terrific convulsions then took place from time to time in Ischia (Pithecusa), and seem to have extended to the neighbouring isle of Procida (Prochyta); for Strabo* mentions a story of Procida having been torn asunder from Ischia; and Pliny† derives its name from its having been poured forth by an eruption from Ischia.

The present circumference of Ischia along the water's edge is eighteen miles, its length from west to east about five, and its breadth from north to south three miles. Several Greek colonies which settled there before the Christian era were compelled to abandon it in consequence of the violence of the eruptions. First the Erythræans, and afterwards the Chalcidians, are mentioned as having been driven out by earthquakes and igneous exhalations. A colony was afterwards established by Hierò, king of Syracuse,

* Lib. v.

† Nat. Hist. lib. iii. c. 6.

about 380 years before the Christian era; but when they had built a fortress, they were compelled by an eruption to fly, and never again returned. Strabo tells us that Timæus recorded a tradition, that, a little before his time, Epomeus, the principal mountain in the centre of the island, vomited fire during great earthquakes; that the land between it and the coast had ejected much fiery matter, which flowed into the sea, and that the sea receded for the distance of three stadia, and then returning, overflowed the island. This eruption is supposed by some to have been that which formed the crater of Monte Corvo on one of the higher flanks of Epomeo, above Foria, the lava-current of which may still be traced, by aid of the scoriæ on its surface, from the crater to the sea.

To one of the subsequent eruptions in the lower parts of the isle, which caused the expulsion of the first Greek colony, Monte Rotaro has been attributed, and it bears every mark of recent origin. The cone is remarkably perfect, and has a crater on its summit precisely resembling that of Monte Nuovo near Naples; but the hill is larger, and resembles some of the more considerable cones of single eruption near Clermont in Auvergne, and, like some of them, it has given vent to a lava-stream at its base, instead of its summit. A small ravine swept out by a torrent exposes the structure of the cone, which is composed of innumerable inclined and slightly undulating layers of pumice, scoriæ, white lapilli, and enormous angular blocks of trachyte. These last have evidently been thrown out by violent explosions, like those which in 1822 launched from Vesuvius a mass of augitic lava, of many tons weight, to the distance of three miles, which fell in the garden of Prince Ottajano. The cone of Rotaro

is covered with the arbutus, and other beautiful evergreens. Such is the strength of the virgin soil, that the shrubs have become almost arborescent; and the growth of some of the smaller wild plants has been so vigorous, that botanists have scarcely been able to recognize the species.

The eruption which dislodged the Syracusan colony is supposed to have given rise to that mighty current which forms the promontory of Zaro and Caruso. The surface of these lavas is still very arid and bristling, and is covered with black scoriæ; so that it is not without great labour that human industry has redeemed some small spots, and converted them into vineyards. Upon the produce of these vineyards the population of the island is almost entirely supported. It amounts at present to about twenty-five thousand, and is on the increase.

From the date of the great eruption last alluded to, down to our own time, Ischia has enjoyed tranquillity, with the exception of one emission of lava hereafter to be described, which, although it occasioned much local damage, does not appear to have devastated the whole country, in the manner of more ancient explosions. There are, upon the whole, on different parts of Epomeo, or scattered through the lower tracts of Ischia, twelve considerable volcanic cones, which have been thrown up since the island was raised above the surface of the deep; and many streams of lava may have flowed, like that of "Arso" in 1302, without cones having been produced; so that this island may, for ages before the period of the remotest traditions, have served as a safety-valve to the whole Terra di Lavoro, while the fires of Vesuvius were dormant.

Lake Avernus. — It seems also clear that Avernus,

a circular lake near Puzzuoli, about half a mile in diameter, which is now a salubrious and cheerful spot, once exhaled mephitic vapours, such as are often emitted by craters after eruptions. There is no reason for discrediting the account of Lucretius, that birds could not fly over it without being stifled, although they may now frequent it uninjured.* There must have been a time when this crater was in action; and for many centuries afterwards it may have deserved the appellation of "atri janua Ditis," emitting, perhaps, gases as destructive of animal life as those suffocating vapours given out by Lake Quilotoa, in Quito, in 1797, by which whole herds of cattle on its shores were killed,† or as those deleterious emanations which annihilated all the cattle in the island of Lancerote, one of the Canaries, in 1730.‡ Bory St. Vincent mentions, that in the same isle birds fell lifeless to the ground; and Sir William Hamilton informs us that he picked up dead birds on Vesuvius during an eruption.

Solfatara. — The Solfatara, near Puzzuoli, which may be considered as a nearly extinguished crater, appears, by the accounts of Strabo and others, to have been before the Christian era in very much the same state as at present, giving vent continually to aqueous vapour, together with sulphureous and muriatic acid gasses, like those evolved by Vesuvius.

Ancient history of Vesuvius. — Such, then, were the

* De Rerum Nat. vi. 740. — Forbes, on Bay of Naples, Edin. Journ. of Sci., No. iii., new series, p. 87. Jan. 1830.

† Humboldt, Voy., p. 317.

‡ Von Buch, Uber einen vulcanischen Ausbruch auf der Insel Lanzerote.

points where the subterranean fires obtained vent, from the earliest period to which tradition reaches back, down to the first century of the Christian era; but we then arrive at a crisis in the volcanic action of this district — one of the most interesting events witnessed by man during the brief period throughout which he has observed the physical changes on the earth's surface. From the first colonization of Southern Italy by the Greeks, Vesuvius afforded no other indications of its volcanic character than such as the naturalist might infer, from the analogy of its structure to other volcanos. These were recognized by Strabo, but Pliny did not include the mountain in his list of active vents. The ancient cone was a very regular form, terminating, not as at present, in two peaks, but with a flattish summit, where the remains of an ancient crater, nearly filled up, had left a slight depression, covered in its interior by wild vines, and with a sterile plain at the bottom. On the exterior, the flanks of the mountains were clothed with fertile fields richly cultivated, and at its base were the populous cities of Herculaneum and Pompeii. But the scene of repose was at length doomed to cease, and the volcanic fire was recalled to the main channel, which, at some former unknown period had given passage to repeated streams of melted lava, sand, and scoriæ.

Renewal of its eruptions.— The first symptom of the revival of the energies of this volcano was the occurrence of an earthquake in the year 63 after Christ, which did considerable injury to the cities in its vicinity. From that time to the year 79 slight shocks were frequent; and in the month of August of that year they became more numerous and violent, till they ended at length in an eruption. The elder Pliny, who

commanded the Roman fleet, was then stationed at Misenum; and in his anxiety to obtain a near view of the phenomena, he lost his life, being suffocated by sulphureous vapours. His nephew, the younger Pliny, remained at Misenum, and has given us, in his Letters, a lively description of the awful scene. A dense column of vapour was first seen rising vertically from Vesuvius, and then spreading itself out laterally, so that its upper portion resembled the head, and its lower the trunk of the pine, which characterizes the Italian landscape. This black cloud was pierced occasionally by flashes of fire as vivid as lightning, succeeded by darkness more profound than night. Ashes fell even upon the ships at Misenum, and caused a shoal in one part of the sea — the ground rocked, and the sea receded from the shores, so that many marine animals were seen on the dry sand. The appearances above described agree perfectly with those witnessed in more recent eruptions, especially those of Monte Nuovo in 1538, and of Vesuvius in 1822.

Silence of Pliny respecting the destruction of Herculaneum and Pompeii.— In all times and countries, indeed, there is a striking uniformity in the volcanic phenomena; but it is most singular that Pliny, although giving a circumstantial detail of so many physical facts, and describing the eruption, earthquake, and shower of ashes which fell at Stabiæ, makes no allusion to the sudden overwhelming of two large and populous cities, Herculaneum and Pompeii. All naturalists who have searched into the memorials of the past for records of physical events, must have been surprised at the indifference with which the most memorable occurrences are often passed by, in the works of writers of enlightened periods; as also of the extraordinary ex-

aggeration which usually displays itself in the traditions of similar events, in ignorant and superstitious ages. But no omission is more remarkable than that now under consideration: nor has the circumstance been at all explained by the suggestion that the chief object of the younger Pliny was to give Tacitus a full account of the particulars of his uncle's death. Had the buried cities never been discovered, the accounts transmitted to us of their tragical end would have been discredited by the majority, so vague and general are the narratives, or so long subsequent to the event. Tacitus, the friend and contemporary of Pliny, when adverting in general terms to the convulsions, says merely that "cities were consumed or buried." *

Suetonius, although he alludes to the eruption incidentally, is silent as to the cities. They are mentioned by Martial, in an epigram, as immersed in cinders; but the first historian who alludes to them by name is Dion Cassius,† who flourished about a century and a half after Pliny. He appears to have derived his information from the traditions of the inhabitants, and to have recorded, without discrimination, all the facts and fables which he could collect. He tells us, "that during the eruption a multitude of men of superhuman stature, resembling giants, appeared, sometimes on the mountain, and sometimes in the environs — that stones and smoke were thrown out, the sun was hidden, and then the giants seemed to rise again, while the sounds of trumpets were heard, &c. &c.; and finally," he relates, "two entire cities, Herculaneum and Pompeii, were buried under showers of ashes, while all the

* Haustæ aut obrutæ urbes.— Hist. lib. i.

† Hist. Rom. lib. lxvi.

people were sitting in the theatre." That many of these circumstances were invented, would have been obvious, even without the aid of Pliny's letters; and the examination of Herculaneum and Pompeii enables us to prove, that none of the people were destroyed in the theatres, and, indeed, that there were very few of the inhabitants who did not escape from both cities. Yet some lives were lost, and there was ample foundation for the tale in its most essential particulars.

This case may often serve as a caution to the geologist, who has frequent occasion to weigh, in like manner, negative evidence derived from the silence of eminent writers, against the obscure but positive testimony of popular traditions. Some authors, for example, would have us call in question the reality of the Ogygian deluge, because Homer and Hesiod say nothing of it. But they were poets, not historians, and they lived many centuries after the latest date assigned to the catastrophe. Had they even lived at the time of that flood, we might still contend that their silence ought, no more than Pliny's, to avail against the authority of tradition, however much exaggeration we may impute to the traditional narrative of the event.

It does not appear that in the year 79 any lava flowed from Vesuvius; the ejected substances, perhaps, consisted entirely of lapilli, sand, and fragments of older lava, as when Monte Nuovo, was thrown up in 1538. The first era at which we have authentic accounts of the flowing of a stream of lava, is the year 1036, which is the seventh eruption from the revival of the fires of the volcano. A few years afterwards, in 1049, another eruption is mentioned, and another in 1138 (or 1139,) after which a great pause ensued

of 168 years. During this long interval of repose, two minor vents opened at distant points. First, it is on tradition that an eruption took place from the Solfatara in the year 1198, during the reign of Frederic II., Emperor of Germany; and although no circumstantial detail of the event has reached us from those dark ages, we may receive the fact without hesitation.* Nothing more, however, can be attributed to this eruption, as Mr. Scrope observes, than the discharge of a light and scoriform trachytic lava, of recent aspect, resting upon the strata of loose tuff which covers the principal mass of trachyte.†

Volcanic eruption in Ischia, 1302.—The other occurrence is well authenticated,—the eruption, in the year 1302, of a lava-stream from a new vent on the south-east side of the Island of Ischia. During part of 1301, earthquakes had succeeded one another with fearful rapidity; and they terminated at last with the discharge of a lava-stream from a point named the Campo del Arso, not far from the town of Ischia. This lava ran quite down to the sea — a distance of about two miles; in colour it varies from iron grey to reddish black, and is remarkable for the glassy felspar which it contains. Its surface is almost as sterile, after a period of five centuries, as if it had cooled down yesterday. A few scantlings of wild thyme, and two or three other dwarfish plants, alone appear in the interstices of the scoriæ, while the Vesuvian lava of 1767 is already covered with a luxuriant vegetation. Pontanus, whose country-house was burnt and over-

* The earliest authority, says Mr. Forbes, given for this fact, appears to be Capaccio, quoted in the Terra Tremante of Bonito. —Edin. Journ. of Sci. &c., No. i., new series, p. 127. July, 1829.

† Geol. Trans. second series, vol. ii. p. 346.

whelmed, describes the dreadful scene as having lasted two months.* Many houses were swallowed up, and a partial emigration of the inhabitants followed. This eruption produced no cone, but only a slight depression, hardly deserving the name of a crater, where heaps of black and red scoriæ lie scattered around. Until this eruption, Ischia is generally believed to have enjoyed an interval of rest for about seventeen centuries; but Julius Obsequens†, who flourished A. D. 214, refers to some volcanic convulsions in the year 662 after the building of Rome (91 B. C.). As Pliny, who lived a century before Obsequens, does not enumerate this among other volcanic eruptions, the statement of the latter author is supposed to have been erroneous; but it would be more consistent, for reasons before stated, to disregard the silence of Pliny, and to conclude that some kind of subterranean commotion, probably of no great violence, happened at the period alluded to.

History of Vesuvius after 1138.— To return to Vesuvius: — the next eruption occurred in 1306; between which era and 1631 there was only one other (in 1500), and that a slight one. It has been remarked, that throughout this period Etna was in a state of such unusual activity as to lend countenance to the idea that the great Sicilian volcano may sometimes serve as a channel of discharge to elastic fluids and lava that would otherwise rise to the vents in Campania.

Formation of Monte Nuovo, 1538.— The great pause was also marked by a memorable event in the Phlegræan Fields — the sudden formation of a new moun-

* Lib. vi. de Bello Neap. in Grævii Thesaur.

† Prodig. libel. c. cxiv.

tain in 1538, of which we have received authentic accounts from contemporary writers.

Fig. 28.

Monte Nuovo, formed in the Bay of Baiæ, Sept. 29th, 1538.

1, Cone of Monte Nuovo. 2, Brim of crater of ditto.
3, Thermal spring, called Baths of Nero, or Stufe di Tritoli.

The height of Monte Nuovo has recently been determined, by the Italian mineralogist Pini, to be 440 English feet above the level of the bay; its base is about eight thousand feet, or more than a mile and a half, in circumference. According to Pini, the depth of the crater is 421 English feet from the summit of the hill, so that its bottom is only nineteen feet above the level of the sea. The cone is declared, by the best authorities, to stand partly on the site of the Lucrine Lake (4, fig. 29.*), which was nothing more than the crater

* This representation of the Phlegræan Fields is reduced from part of Plate xxxi. of Sir William Hamilton's great work, "Campi Phlegræi." The faithfulness of his coloured delineations of the scenery of that country cannot be too highly praised.

of a pre-existent volcano, and was almost entirely filled during the explosion of 1538. Nothing now remains but a shallow pool, separated from the sea by an elevated beach, raised artificially.

Fig. 29.

The Phlegræan Fields.

1, Monte Nuovo. 4, Lucrine Lake.
2, Monte Barbaro. 5, The Solfatara.
3, Lake Avernus. 6, Puzzuoli.
7, Bay of Baiæ.

Sir William Hamilton has given us two original letters describing this eruption. The first, by Falconi, dated 1538, contains the following passages.* "It is now two years since there have been frequent earthquakes at Puzzuoli, Naples, and the neighbouring parts. On the day and in the night before the eruption (of Monte Nuovo), above twenty shocks, great and small, were felt. The eruption began on the 29th of September, 1538. It was on a Sunday, about one o'clock in the night, when flames of fire were seen

* Campi Phlegræi, p. 70.

between the hot baths and Tripergola. In a short time the fire increased to such a degree, that it burst open the earth in this place, and threw up so great a quantity of ashes and pumice stones, mixed with water, as covered the whole country. The next morning (after the formation of Monte Nuovo) the poor inhabitants of Puzzuoli quitted their habitations in terror, covered with the muddy and black shower which continued the whole day in that country — flying from death, but with death painted in their countenances. Some with their children in their arms, some with sacks full of their goods; others leading an ass, loaded with their frightened family, towards Naples; others carrying quantities of birds, of various sorts, that had fallen dead at the beginning of the eruption; others, again, with fish which they had found, and which were to be met with in plenty on the shore, the sea having left them dry for a considerable time. I accompanied Signor Moramaldo to behold the wonderful effects of the eruption. The sea had retired on the side of Baiæ, abandoning a considerable tract, and the shore appeared almost entirely dry, from the quantity of ashes and broken pumice stones thrown up by the eruption. I saw two springs in the newly discovered ruins; one before the house that was the queen's, of hot and salt water," &c.

So far Falconi; the other account is by Pietro Giacomo di Toledo, which begins thus:— "It is now two years since this province of Campagna has been afflicted with earthquakes, the country about Puzzuoli much more so than any other parts: but the 27th and the 28th of the month of September last, the earthquakes did not cease day or night in the town of Puzzuoli: that plain which lies between Lake Avernus,

the Monte Barbaro, and the sea, was *raised a little*, and many cracks were made in it, from some of which issued water; at the same time the sea immediately adjoining the plain *dried up about two hundred paces*, so that the fish were left on the sand a prey to the inhabitants of Puzzuoli. At last, on the 29th of the same month, about two o'clock in the night, the earth opened near the lake, and discovered a horrid mouth, from which were vomited furiously smoke, fire, stones, and mud, composed of ashes, making at the time of its opening a noise like the loudest thunder. The stones which followed were by the flames converted to pumice, and some of these were *larger than an ox*. The stones went about as high as a cross-bow can carry, and then fell down, sometimes on the edge, and sometimes into the mouth itself. The mud was of the colour of ashes, and at first very liquid, then by degrees less so, and in such quantities, that in less than twelve hours, with the help of the above-mentioned stones, a mountain was raised of 1000 paces in height. Not only Puzzuoli and the neighbouring country was full of this mud, but the city of Naples also; so that many of its palaces were defaced by it. Now this eruption lasted two nights and two days without intermission, though, it is true, not always with the same force; the third day the eruption ceased, and I went up with many people to the top of the new hill, and saw down into its mouth, which was a round cavity, about a quarter of a mile in circumference, in the middle of which the stones which had fallen were boiling up, just as a caldron of water boils on the fire. The fourth day it began to throw up again, and the seventh much more, but still with less violence than the first night. At this time many persons who were

on the hill were knocked down by the stones and killed, or smothered with the smoke. In the day the smoke still continues, and you often see fire in the midst of it in the night-time." *

It will be seen that both these accounts, written immediately after the birth of Monte Nuovo, agree in stating that the sea retired; and one mentions that its bottom was upraised; but they attribute the origin of the new hill exclusively to the jets of mud, showers of scoriæ, and large fragments of rock, cast out from a central orifice for several days and nights. Baron Von Buch, however, in his excellent work on the Canary Islands, and volcanic phenomena in general, has declared his opinion that the cone and crater of Monte Nuovo were formed, not in the manner above described, but by the upheaval of solid beds of white tuff, which were previously horizontal, but which were pushed up in 1538, so as to dip away in all directions from the centre, with the same inclination as the sloping surface of the cone itself. "It is an error," he says, "to imagine that this hill was formed by eruption, or by the ejection of pumice, scoriæ, and other incoherent matter; for the solid beds of upraised tuff are visible all round the crater, and it is merely the superficial covering of the cone which is made up of ejected scoriæ.†

In confirmation of this view, M. Dufrénoy has recently cited a passage from the works of Porzio, a celebrated physician of that period, to prove that in 1538 the ground where Monte Nuovo stands was pushed up in the form of a great bubble or blister, which on bursting, gave origin to the present deep crater. Porzio says, "that after two days and nights of

* Campi Phlegræi, p. 77.

† P. 347. Paris, 1836.

violent earthquakes, the sea retired for nearly 200 yards; so that the inhabitants could collect great numbers of fish on this part of the shore, and see some springs of fresh water which rose up there. At length, on the third day of the calends of October (September 29th), they saw a large tract of ground intervening between the foot of Monte Barbaro and part of the sea, near the Lake Avernus, rise, and suddenly assume the form of an incipient hill; and at two o'clock at night, this heap of earth, opening as it were its mouth, vomited, with a loud noise, flames, pumice stones, and ashes."*

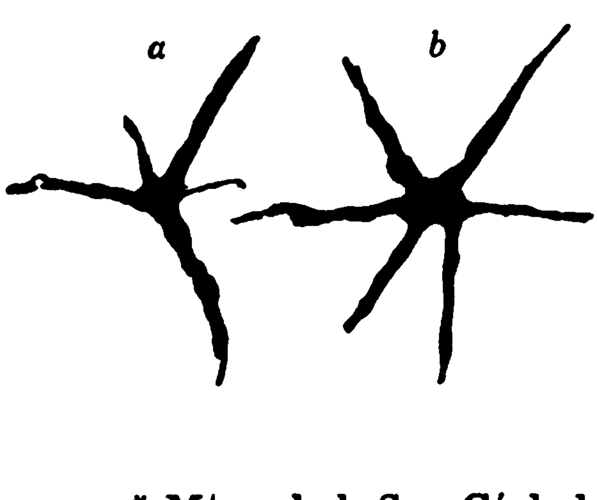
On considering the more detailed accounts of the eye-witnesses Falconi and Toledo, I am inclined to believe that on the night of the 29th, a gulf opened between Tripergola and the baths in its suburbs, and that mud, pumice, and large solid blocks of stone were discharged from the chasm, so as to bury the town, and throw up a considerable hill in less than twenty-four hours, in the same manner as on a smaller scale the mud cones of air volcanos are produced, with a cavity in the middle. There is no difficulty in conceiving that the pumiceous mud, if so thrown out, may have set into a kind of stone on drying, just as some cements, composed of volcanic ashes, are known

* "Magnus terræ tractus, qui inter radices montis, quem Barbarum incolæ appellant, et mare juxta Avernum jacet, sese erigere videbatur, et montis subitò nascentis figuram imitari. Eo ipso die horâ noctis II., iste terræ cumulus, aperto veluti ore, magno cum fremitu, magnos ignes evomuit; pumicesque, et lapides, cineresque." — Porzio, Opera Omnia, Medica, Phil., et Mathemat., in unum collecta, 1736, cited by Dufrénoy, Mém. pour servir à une Description Géologique de la France, tom. iv. p. 274.

to consolidate with facility. Tripergola was much frequented as a watering place, and contained a hospital for those who resorted there for the benefit of the thermal springs; and it appears that there were no fewer than three inns in the principal street. Had Porzio stated that any of these buildings, or the ruins of them, were seen by himself or others raised up above the plain, a short time before the first eruption, so as to stand on the summit or slope of a newly-raised hillock, we might have been compelled, by so circumstantial a narrative, to adopt M. Dufrénoy's interpretation.

But in the absence of such evidence, we must appeal to the crater itself, where we behold a section of the whole mountain, without being able to detect any original nucleus of upheaved rock distinct from the rest; on the contrary, the whole mass is similar throughout in composition, and the cone very symmetrical in form; nor are there any clefts, such as might be looked for as the effect of the sudden upthrow of stony masses. M. C. Prevost has well remarked, that if beds of solid and non-elastic materials had yielded to a violent pressure directed from below upwards, we should find not simply a deep empty cavity, but an irregular opening, where many rents converged; and these rents would be now seen breaking through the walls of the crater, widening as they approach the centre. (See fig. 30. *a, b.*)* Not

Fig. 30.



* Mém. de la Soc. Géol. de France, tom. ii. p. 91.

a single fissure of this kind is observable in the interior of Monte Nuovo, where the walls of the crater are continuous and entire; nor are there any dikes implying that rents had existed, which were afterwards filled with lava or other matter.

It has moreover been often urged by Von Buch, De Beaumont, and others, who ascribe the conical form of volcanos chiefly to upheaval from below, that in such mountains there are a great number of deep rents and ravines, which diverge on all sides like the spokes of a wheel, from near the central axis to the circumference or base of the cone, as in the case of Palma, Cantal, and Teneriffe. Yet the entire absence of such divergent fissures or ravines, in such cases as Monte Nuovo, Somma, or Etna, is passed by unnoticed, and appears to have raised in their minds no objection to their favourite theory.

It is, indeed, admitted by M. Dufrénoy that there are some facts which it is very difficult to reconcile with his own view of Porzio's record. Thus, for example, there are certain Roman monuments at the base of Monte Nuovo, and on the borders of Lake Avernus, such as the temples of Apollo and Pluto, which do not seem to have suffered in the least degree by the supposed upheaval. "The walls which still exist have preserved their vertical position, and the vaults are in the same state as other monuments on the shores of the Bay of Baiæ. The long gallery which led to the Sibyl's Cave, on the other side of Lake Avernus, has in like manner escaped injury, the roof of the gallery remaining perfectly horizontal, the only change being that the soil of the chamber in which the Sibyl gave out her oracles is now covered by a few

inches of water, which merely indicates a slight alteration in the level of Lake Avernus."* On the supposition, then, that pre-existing beds of pumiceous tuff were upraised in 1538, so as to form Monte Nuovo, it is acknowledged that the perfectly undisturbed state of the contiguous soil on which these ancient monuments stand, is very different from what might have been expected.

I shall again revert to the doctrine of the origin of volcanic cones by upheaval, when speaking of Vesuvius and Etna, and I shall now merely add, that in 1538, the whole coast, from Monte Nuovo to beyond Puzzuoli, was upraised to the height of many feet above the bed of the Mediterranean, and has since retained the greater part of the elevation then acquired. The proofs of these remarkable changes of level will be considered at length when the phenomena of the Temple of Serapis are described.†

Volcanos of the Phlegræan Fields. — Immediately adjoining Monte Nuovo is the larger volcanic cone of Monte Barbaro (2. fig. 29.), the Gaurus inanis of Juvenal — an appellation given to it probably from its deep circular crater, which is about a mile in diameter. Large as is this cone, it was probably produced by a single eruption; and it does not, perhaps, exceed in magnitude some of the largest of those formed in Ischia, within the historical era. It is composed chiefly of indurated tufa like Monte Nuovo, stratified conformably to its conical surface. This hill was once very celebrated for its wines, and is still covered with vineyards; but when the vine is not in leaf it has a sterile appearance, and, late in the year, when seen

* Dufrénoy, Mém. pour servir, &c. p. 277. † See chap. xvii.

from the beautiful bay of Baiæ, it often contrasts so strongly in verdure with Monte Nuovo, which is always clothed with arbutus, myrtle, and other wild evergreens, that a stranger might well imagine the cone of older date to be that thrown up in the sixteenth century.*

There is nothing, indeed, so calculated to instruct the geologist as the striking manner in which the recent volcanic hills of Ischia, and that now under consideration, blend with the surrounding landscape. Nothing seems wanting or redundant; every part of the picture is in such perfect harmony with the rest, that the whole has the appearance of having been called into existence by a single effort of creative power. Yet what other result could we have anticipated, if Nature has ever been governed by the same laws? Each new mountain thrown up — each new tract of land raised or depressed by earthquakes — should be in perfect accordance with those previously formed, if the entire configuration of the surface has been due to a long series of similar disturbances. Were it true that the greater part of the dry land originated simultaneously in its present state, at some era of paroxysmal convulsion, and that additions were afterwards made slowly and successively during a period of comparative repose; then, indeed, there might be reason to expect a strong line of demarcation between the signs of ancient and modern changes. But the very continuity of the plan, and the perfect identity of the causes, are to many a source of decep-

* Hamilton (writing in 1770) says, "the new mountain produces as yet but a very slender vegetation." — Campi Phlegræi, p. 69. This remark was no longer applicable when I saw it, in 1828.

tion; since, by producing a unity of effect, they lead them to exaggerate the energy of the agents which operated in the earlier ages. In the absence of all historical information, they are as unable to separate the dates of the origin of different portions of our continents, as the stranger is to determine, by their physical features alone, the distinct ages of Monte Nuovo, Monte Barbaro, Astroni, and the Solfatara.

The vast scale and violence of the volcanic operations in Campania, in the olden time, has been a theme of declamation, and has been contrasted with the comparative state of quiescence of this delightful region in the modern era. Instead of inferring, from analogy, that the ancient Vesuvius was always at rest when the craters of the Phlegræan Fields were burning,— that each cone rose in succession,— and that many years, and often centuries, of repose intervened between different eruptions,— geologists seem to have generally conjectured that the whole group sprung up from the ground at once, like the soldiers of Cadmus when he sowed the dragon's teeth. As well might they endeavour to persuade us that on these Phlegræan Fields, as the poets feigned, the giants warred with Jove, ere yet the puny race of mortals were in being.

Modern eruptions of Vesuvius.— For nearly a century after the birth of Monte Nuovo, Vesuvius continued in a state of tranquillity. There had then been no violent eruption for 492 years; and it appears that the crater was then exactly in the condition of the present extinct volcano of Astroni, near Naples. Bracini, who visited Vesuvius not long before the eruption of 1631, gives the following interesting description of the interior:— "The crater was five miles in circumference, and about a thousand paces deep; its sides

were covered with brushwood, and at the bottom there was a plain on which cattle grazed. In the woody parts wild boars frequently harboured. In one part of the plain, covered with ashes, were three small pools, one filled with hot and bitter water, another salter than the sea, and a third hot, but tasteless." * But at length these forests and grassy plains were consumed, being suddenly blown into the air, and their ashes scattered to the winds. In December, 1631, seven streams of lava poured at once from the crater, and overflowed several villages on the flanks and at the foot of the mountain. Resina, partly built over the ancient site of Herculaneum, was consumed by the fiery torrent. Great floods of mud were as destructive as the lava itself,—no uncommon occurrence during these catastrophes; for such is the violence of rains produced by the evolution of aqueous vapour, that torrents of water descend the cone, and, becoming charged with impalpable volcanic dust, and rolling along loose ashes, acquire sufficient consistency to deserve their ordinary appellation of "aqueous lavas."

A brief period of repose ensued, which lasted only until the year 1666, from which time to the present there has been a constant series of eruptions, with rarely an interval of rest exceeding ten years. During these three centuries, no irregular volcanic agency has convulsed other points in this district. Brieslak remarked, that such irregular convulsions had occurred in the Bay of Naples in every second century; as, for example, the eruption of the Solfatara, in the twelfth, of the lava of Arso, in Ischia, in the fourteenth, and of

* Hamilton's Campi Phlegræi, folio, vol. i. p. 62.; and Brieslak, Campanie, tome, i. p. 186.

Monte Nuovo in the sixteenth: but the eighteenth has formed an exception to this rule, and this seems accounted for by the unprecedented number of eruptions of Vesuvius during that period; whereas, when the new vents opened, there had always been, as we have seen, a long intermittance of activity in the principal volcano.

CHAPTER XII.

VOLCANIC DISTRICT OF NAPLES — *continued.*

Dimensions and structure of the cone of Vesuvius — Dikes — Lavas and minerals — Alluviums called "aqueous lavas"— Origin and composition of the matter enveloping Herculaneum and Pompeii — Condition and contents of the buried cities — Small number of skeletons — State of preservation of animal and vegetable substances — Rolls of papyrus — Stabiæ — Torre del Greco — Concluding remarks on the Campanian volcanos.

Structure of the cone of Vesuvius.— BETWEEN the end of the eighteenth century and the year 1822, the great crater of Vesuvius had been gradually filled by lava boiling up from below, and by scoriæ falling from the explosions of minor mouths which were formed at intervals on its bottom and sides. In place of a regular cavity, therefore, there was a rough and rocky plain, covered with blocks of lava and scoriæ, and cut by numerous fissures, from which clouds of vapour were evolved. But this state of things was totally changed by the eruption of October, 1822, when violent explosions, during the space of more than twenty days, broke up and threw out all this accumulated mass, so as to leave an immense gulf or chasm, of an irregular, but somewhat elliptical shape, about three miles in circumference when measured along the very sinuous and irregular line of its extreme margin, but somewhat

less than three quarters of a mile in its longest diameter, which was directed from N.E. to S.W.* The depth of this tremendous abyss has been variously estimated; for from the hour of its formation it decreased daily by the dilapidation of its sides. It measured, at first, according to the account of some authors, two thousand feet in depth from the extreme part of the existing summit†; but Mr. Scrope, when he saw it, soon after the eruption, estimated its depth at less than half that amount. More than eight hundred feet of the cone was carried away by the explosions, so that the mountain was reduced in height from about 4200 to 3400 feet.‡

As we ascend the sloping sides, the volcano appears a mass of loose materials — a mere heap of rubbish, thrown together without the slightest order; but on arriving at the brim of the crater, and obtaining a view of the interior, we are agreeably surprised to discover that the confirmation of the whole displays in every part the most perfect symmetry and arrangement. The materials are disposed in regular strata, slightly undulating, appearing, when viewed in front, to be disposed in horizontal planes. But, as we make the circuit of the edge of the crater, and observe the cliffs by which it is encircled projecting or receding in salient or retiring angles, we behold transverse sections of the currents of lava and beds of sand and scoriæ, and recognize their true dip. We then discover that

* Account of the Eruption of Vesuvius in October, 1822, by G. P. Scrope, Esq., Journ., of Sci., &c. vol. xv. p. 175.

† Mr. Forbes, Account of Mount Vesuvius, Edin. Journ. of Sci., No. xviii. p. 195. Oct. 1828.

‡ Ibid. p. 194.

they incline outwards from the axis of the cone, at angles varying from 30° to 45°. The whole cone, in fact, is composed of a number of concentric coatings of alternating lavas, sand, and scoriæ. Every shower of ashes which has fallen from above, and every stream of lava descending from the lips of the crater, have conformed to the outward surface of the hill, so that one conical envelope may be said to have been successively folded round another, until the aggregation of the whole mountain was completed. The marked separation into distinct beds results from the different colours and degrees of coarseness in the sands, scoriæ, and lava, and the alternation of these with each other. The greatest difficulty, on the first view, is to conceive how so much regularity can be produced, notwithstanding the unequal distribution of sand and scoriæ, driven by prevailing winds in particular eruptions, and the small breadth of each sheet of lava as it first flows out from the crater.

But on a closer examination, we find that the appearance of extreme uniformity is delusive, for when a number of beds thin out gradually, and at different points, the eye does not without difficulty recognize the termination of any one stratum, but usually supposes it continuous with some other, which at a short distance may lie precisely in the same plane. The slight undulations, moreover, produced by inequalities on the sides of the hill on which the successive layers were moulded, assist the deception. As countless beds of sand and scoriæ constitute the greater part of the whole mass, these may sometimes mantle continuously round the whole cone; and even lava-streams may be of considerable breadth when first they overflow; and, since in some eruptions, a considerable part

of the upper portion of the cone breaks down at once, may form a sheet extending as far as the space which the eye usually takes in in a single section.

The high inclination of some of the beds, and the firm union of the particles even where there is evidently no cement, is another striking feature in the volcanic tuffs and breccias, which seems at first not very easy of explanation. But the last great eruption afforded ample illustration of the manner in which these strata are formed. Fragments of lava, scoriæ, pumice, and sand, when they fall at slight distances from the summit, are only half cooled down from a state of fusion, and are afterwards acted upon by the heat from within, and by fumeroles or small crevices in the cone through which hot vapours are disengaged. Thus heated, the ejected fragments cohere together strongly; and the whole mass acquires such consistency in a few days, that fragments cannot be detached without a smart blow of the hammer. At the same time sand and scoriæ, ejected to a greater distance, remain incoherent.*

Sir William Hamilton, in his description of the eruption of 1779, says, that jets of liquid lava, mixed with stones and scoriæ, were thrown up to the height of at least ten thousand feet, having the appearance of a column of fire.† Some of these were directed by the winds towards Ottajano, and some of them, falling almost perpendicularly, still red hot and liquid, on Vesuvius, covered its whole cone, part of the mountain of Somma, and the valley between them. The falling matter being nearly as vividly

* Monticelli and Covelli, Storia di Fenon. del Vesuv., en 1821-2-3.

† Campi Phlegræi.

inflamed as that which was continually issuing fresh from the crater, formed with it one complete body of fire, which could not be less than two miles and a half in breadth, and of the extraordinary height above mentioned, casting a heat to the distance of at least six miles around it. Dr. Clarke, also, in his account of the eruption of 1793, says that millions of red-hot stones were shot into the air full half the height of the cone itself, and then bending, fell all around in a fine arch. On another occasion he says that, as they fell, they covered nearly half the cone with fire.

The same author has also described the different appearance of the lava at its source, and at some distance from it, when it had descended into the plains below. At the point where it issued, in 1793, from an arched chasm in the side of the mountain, the vivid torrent rushed with the velocity of a flood. It was in perfect fusion, unattended with any scoriæ on its surface, or any gross materials not in a state of complete solution. It flowed with the translucency of honey, "in regular channels, cut finer than art can imitate, and glowing with all the splendour of the sun."—"Sir William Hamilton," he continues, "had conceived that no stones thrown upon a current of lava would make any impression. I was soon convinced of the contrary. Light bodies, indeed, of five, ten, and fifteen pounds weight made little or no impression even at the source; but bodies of sixty, seventy, and eighty pounds were seen to form a kind of bed on the surface of the lava, and float away with it. A stone of three hundred weight, that had been thrown out by the crater, lay near the source of the current of lava: I raised it upon one end, and then let it fall in upon the liquid lava; when it gradually sunk

beneath the surface, and disappeared. If I wished to describe the manner in which it acted upon the lava, I should say that it was like a loaf of bread thrown into a bowl of very thick honey, which gradually involves itself in the heavy liquid, and then slowly sinks to the bottom.

"The lava, at a small distance from its source, acquires a darker tint upon its surface, is less easily acted upon, and, as the stream widens, the surface, having lost its state of perfect solution, grows harder and harder, and cracks into innumerable fragments of very porous matter, to which they give the name of scoriæ, and the appearance of which has led many to suppose that it proceeded thus from the mountain. There is, however, no truth in this. All lava, at its first exit from its native volcano, flows out in a liquid state, and all equally in fusion. The appearance of the scoriæ is to be attributed only to the action of the external air, and not to any difference in the materials which compose it, since any lava whatever, separated from its channel, and exposed to the action of the external air, immediately cracks, becomes porous, and alters its form. As we proceeded downward, this became more and more evident; and the same lava which at its original source flowed in perfect solution, undivided, and free from encumbrances of any kind; a little farther down had its surface loaded with scoriæ in such a manner, that, upon its arrival at the bottom of the mountain, the whole current resembled nothing so much as a heap of unconnected cinders from an iron-foundery." In another place he says, that "the rivers of lava in the plain resembled a vast heap of cinders, or the scoriæ of an iron-foundery, rolling

slowly along, and falling with a rattling noise over one another." *

It appears that the intensity of the light and heat of the lava varies considerably at different periods of the same eruption, as in that of Vesuvius in 1819 and 1820, when Sir H. Davy remarked different degrees of vividness in the white heat at the point where the lava originated.†

When the expressions "flame" and "smoke" are used in describing volcanic appearances, they must generally be understood in a figurative sense. We are informed, indeed, by M. Abich that he distinctly saw, in the eruption of Vesuvius in 1834, the flame of burning hydrogen; ‡ but what is usually mistaken for flame consists of vapour or scoriæ, and impalpable dust illuminated by that vivid light which is emitted from the crater below, where the lava is said to glow with the splendour of the sun. The clouds of apparent smoke are formed either of aqueous and other vapour, or of finely comminuted scoriæ.

Dikes in the recent cone, how formed.—The inclined strata before mentioned which dip outwards in all directions from the axis of the cone of Vesuvius, are intersected by veins or dikes of compact lava, for the most part in a vertical position. In 1828 these were seen to be about seven in number, some of them not less than four or five hundred feet in height, and thinning out before they reached the uppermost part of the cone. Being harder than the beds through

* Otter's Life of Dr. Clarke.

† Phil. Trans., 1828, p. 241.

‡ Bulletin de la Soc. Géol. de France, tom. vii. p. 43.; and Illustrations of Vesuvius and Etna, p. 3.

which they pass, they have decomposed less rapidly, and therefore stand out in relief. When I visited Vesuvius, in November 1828, I was prevented from descending into the crater by the constant ejections then thrown out; so that I got sight of three only of the dikes; but Signor Monticelli had previously had drawings made of the whole, which he showed me. The dikes which I saw were on that side of the cone which is encircled by Somma. The eruption before mentioned, of 1828, began in March, and in the November following the ejected matter had filled up nearly one third of the deep abyss formed at the close of the eruption in 1822. In November I found a single black cone at the bottom of the crater continually throwing out scoriæ, while on the exterior of the cone I observed the lava of 1822, which had flowed out six years before, not yet cool, and still evolving much heat and vapour from crevices.

Hoffman, in 1832, saw on the north side of Vesuvius, near the peak called Palo, a great many parallel bands of lava, some from six to eight feet thick, alternating with scoriæ and conglomerate. These beds, he says, were cut through by many dikes, some of them five feet broad. They resemble those of Somma, the stone being composed of grains of leucite and augite.*

There can be no doubt that the dikes above mentioned have been produced by the filling up of open fissures with liquid lava; but of the date of their formation we know nothing further than that they are all subsequent to the year 79, and, relatively speaking, that they are more modern than all the lavas and scoriæ which they intersect. A considerable number

* Geognost. Beobachtungen, &c. p. 182. Berlin, 1839.

of the upper strata are not traversed by them. That the earthquakes, which almost invariably precede eruptions, occasion rents in the mass is well known; and, in 1822, three months before the lava flowed out, open fissures, evolving hot vapours, were numerous. It is clear that such rents must be injected with melted matter when the column of lava rises, so that the origin of the dikes is easily explained, as also the great solidity and crystalline nature of the rock composing them, which has been formed by lava cooling slowly under great pressure.

It has been suggested that the frequent rending of volcanic cones during eruptions may be connected with the gradual and successive upheaval of the whole mass in such a manner as to increase the inclination of the beds composing the cone; and in accordance with the hypothesis before proposed for the origin of Monte Nuovo, Von Buch supposes that the present cone of Vesuvius was formed in the year 79, not by eruption, but by upheaval. It was not produced by the repeated superposition of scoriæ and lava cast out or flowing from a central source, but by the uplifting of strata previously horizontal. The entire cone rose at once, such as we now see it, from the interior and middle of Somma, and has since received no accession of height, but, on the contrary, has ever since been diminishing in elevation.*

Of the facts hitherto known, which may seem to favour this singular hypothesis of Von Buch, none are more deserving of attention than those recorded by M. Abich in his account of the Vesuvian eruptions of

* Von. Buch, Descrip. Phys. des Isles Canaries, p. 342. Paris, 1836.

1833 and 1834, a work illustrated by excellent engravings of the volcanic phenomena which he witnessed.* It appears that, in the year 1834, the great crater of Vesuvius had been filled up nearly to the top with lava, which had consolidated and formed a level and unbroken plain, except that a small cone thrown up by the ejection of scoriæ rose in the middle of it like an island in a lake. At length this plain of lava was broken by a fissure which passed from N. E. to S.W., and along this line a great number of minute cones emitting vapour were formed. The first act of formation of these minor cones is said to have consisted of a partial upheaval of beds of lava previously horizontal, and which had been rendered flexible by the heat and tension of elastic fluids, which rising from below, escaped from the centre of each new monticule. The analogy of this mode of origin with that ascribed by Von Buch to Vesuvius and Somma would be very perfect, if the dimensions of the upraised masses were not on so different a scale, and if it was safe to reason from the inflation of bladders of half-fused lava, from fifteen to twenty-five feet in height, to mountains attaining an altitude of several thousand feet.

At the same time M. Abich mentions, that when, in August 1834, a great subsidence took place in the platform of lava within the great crater, so that the structure of the central cone was laid open, it was seen to have been evidently formed, not by upheaval, but by the fall of cinders and scoriæ which had been thrown out during successive eruptions.†

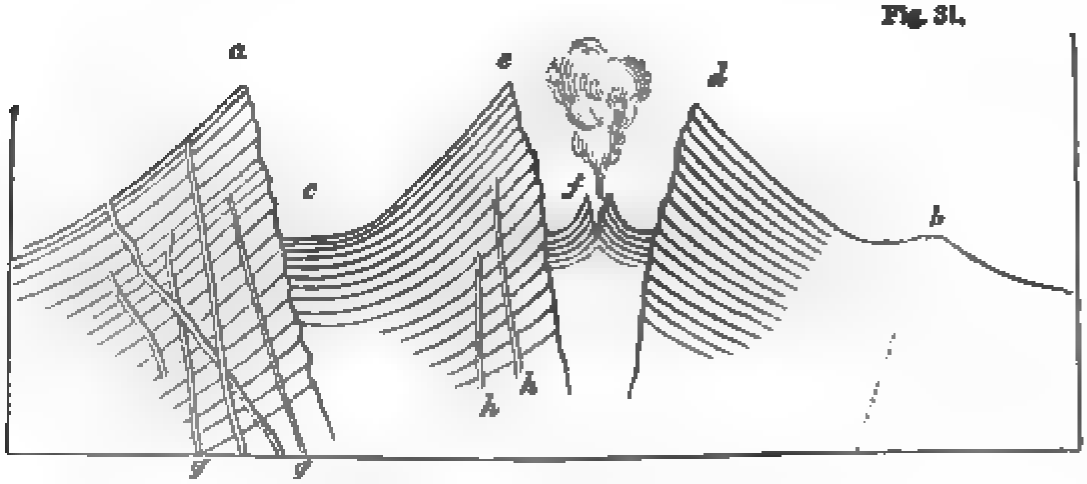
Previous to the year 79, Vesuvius appears, from the

* Vues Illust. de Phénom. Géol. Observ. sur le Vésuve et l'Etna. Berlin, 1837.

† Ibid. p. 2.

description of its figure given by Strabo, to have been a truncated cone, with a crater at its summit; and Brieslak first announced the opinion, which has since been generally adopted, that the eruptions which occurred in 79, and subsequently, destroyed that side of the original cone which was towards the sea, leaving the remainder, now called Somma, encircling a new cone, which was then first thrown up. In the annexed diagram (Fig. 31.) it will be seen that, on the side of Vesuvius opposite to that where a portion of the ancient cone of Somma (*a*) still remains, is a projection (*b*)

Fig. 31.



Supposed section of Vesuvius and Somma.

a, Monte Somma, or the remains of the ancient cone of Vesuvius.

b, The Pedamentina, a terrace-like projection, encircling the base of the recent cone of Vesuvius, on the south side.

c, Atrio del Cavallo.*

d, *e*, Crater left by eruption of 1822.

f, Small cone thrown up in 1828, at the bottom of the great crater.

g, *g*, Dikes intersecting Somma.

h, *h*, Dikes intersecting the recent cone of Vesuvius.

called the Pedamentina, which some have supposed to be part of the circumference of the ancient crater broken down towards the sea, and over the edge of

* So called from travellers leaving their horses and mules there when they prepare to ascend the cone on foot.

which the lavas of the modern Vesuvius have poured; the axis of the present cone of Vesuvius being, according to Visconti, precisely equidistant from the escarpment of Somma and the Pedamentina.

In the same diagram the slanting beds of the cone of Vesuvius are represented as becoming horizontal in the Atrio del Cavallo (at *c*), where the base of the new cone meets the precipitous escarpment of Somma; for when the lava flows down to this point, as happened in 1822, its descending course is arrested, and it then runs in another direction along this small valley, circling round the base of the cone. Sand and scoriæ, also, blown by the winds, collect at the base of the cone, and are then swept away by torrents; so that there is always here a flattish plain, as represented. In the same manner the small interior cone (*f*) must be composed of sloping beds, terminating in a horizontal plain; for, while this monticule was gradually gaining height by successive ejections of lava and scoriæ, in 1828, it was always surrounded by a flat pool of semi-fluid lava, into which scoriæ and sand were thrown.

In the steep semicircular escarpment of Somma, which faces the modern Vesuvius, we see a great number of sheets of lava inclined at an angle of about 26°. They alternate with scoriæ, and are intersected by numerous dikes, which, like the sheets of lava, are composed chiefly of augite, with crystals of leucite, but the rock in the dikes is more compact, having cooled and consolidated under greater pressure. Some of the dikes cut through and shift others, so that they have evidently been formed during successive eruptions. While the higher region of Somma is made up of these igneous products, there appear on its flanks, for some

depth from the surface, as seen in a ravine, called the "Fossa Grande," beds of white pumiceous tuff, resembling the tuff which, at Pausilippo, and other places, near Naples, contains shells of living Mediterranean species. It is supposed by Pilla, Von Buch, and others, that the tufaceous beds, which rise in Somma to more than half the height of that mountain, are, in like manner, of submarine origin, because a few sea-shells have been found in them, here and there, together with serpulæ of recent species attached to included blocks of limestone.*

It is contended, therefore, that, as these strata were once accumulated beneath the sea, they may have been subjected as they rose to such an upward movement as may have given rise to a conical hill; and this hypothesis, it is said, acquires confirmation from the fact, that the sheets of lava near the summit of Somma are so compact and crystalline, and of such breadth individually, as would not have been the case had they run down a steep slope. They must, therefore, have consolidated on a nearly level surface, and have been subsequently uplifted into their present inclined position.

Unfortunately there are no sections of sufficient depth and continuity on the flanks of Somma, to reveal to us clearly the relations of the lava, scoriæ, and associated dikes, forming the highest part of the mountain with the marine tuffs observed on its declivity. Both may, perhaps, have been produced contemporaneously when Somma raised its head, like Stromboli,

* Dufrénoy, Mém. pour servir à une Descrip. Géol. de la France, tom. iv. p. 294.

above the sea, its sides and base being then submerged. Such a state of things may be indicated by a fact noticed by Von Buch, namely, that the pumiceous beds of Naples, when they approach Somma, contain fragments of the peculiar leucitic lava proper to that mountain, which are not found in the same tuff at a greater distance.* Portions, therefore, of this lava were either thrown out by explosions, or torn off by the waves, during the deposition of the pumiceous strata beneath the sea.

We have as yet but a scanty acquaintance with the laws which regulate the flow of lava beneath water, or the arrangement of scoriæ and volcanic dust on the sides of a submarine cone. There can, however, be little doubt that showers of ejected matter may settle on a steep slope, and may include shells and the remains of aquatic animals, which flourish in the intervals between eruptions. Lava under the pressure of water would be less porous, but, as Dr. Daubeny suggests, it may retain its fluidity longer than in the open air; for the rapidity with which heated bodies are cooled by being plunged into water arises chiefly from the conversion of the lower portions of water into steam, which steam absorbing much heat, immediately ascends, and is reconverted into water. But under the pressure of an ocean sufficiently deep to prevent the formation of steam, the heat of the lava would be carried off more slowly, and only by the circulation of ascending and descending currents of water, those portions nearest the source of heat becoming specifically lighter, and consequently displacing the water

* Descrip. Phys. des Iles Canaries, p. 344.

above. This kind of circulation would take place with much less rapidity than in the atmosphere, inasmuch as the expansion of water by equal increments of heat is less considerable than that of air.*

If we admit that the inclined position of the sheets of lava and marine tuffs on Somma may have been partly due to that rending of the cone, which is proved by the dikes to have occurred again and again, we may still believe the form of the mountain to have been principally due to eruptions from a central orifice. It is also in the highest degree probable that the development of the upheaving force, by which the shape of the cone may have been modified, was intermittent and gradual, not concentred, as Von Buch and others have suggested, in one effort of sudden and violent convulsion.

Vesuvian lavas. — The lavas of Somma are characterized by containing disseminated crystals of leucite (called, by the French, amphigène), a mineral said to be very rare in the modern lavas of Vesuvius, which are in general much more scoriaceous and less crystalline than those of Somma.†

At the fortress near Torre del Greco a section is exposed, fifteen feet in height, of a current which ran into the sea; and it evinces, especially in the lower part a decided tendency to divide into rude columns. A still more striking example may be seen to the west of Torre del Annunziata, near Forte Scassato, where the mass is laid open to the depth of twenty feet. In both these cases, however, the rock may rather be said to be divided into numerous perpendicular fissures, than

* See Daubeny's Volcanos, p. 400.

† Dufrénoy, Mém. pour servir, &c., tom. iv. p. 285.

to be prismatic, although the same picturesque effect is produced. In the lava-currents of Central France (those of the Vivarais, in particular), the uppermost portion, often forty feet or more in thickness, is an amorphous mass passing downwards into lava irregularly prismatic; and under this, there is a foundation of regular and vertical columns, but these lavas are often one hundred feet or more in thickness. We can scarcely expect to discover the same phenomenon in the shallow currents of Vesuvius, where the lowest part has cooled more rapidly, although it may be looked for in modern streams in Iceland, which exceed even those of ancient France in volume.

Mr. Scrope mentions that, in the cliffs encircling the modern crater of Vesuvius, he saw many currents offering a columnar division, and some almost as regularly prismatic as any ranges of the older basalts; and he adds, that in some the spheroidal concretionary structure, on a large scale, was equally conspicuous.* Brieslak † also informs us that, in the siliceous lava of 1737, which contains augite, leucite, and crystals of felspar, he found very regular prisms in a quarry near Torre del Greco; an observation confirmed by modern authorities.‡

Effects of decomposition on lavas.—The decomposition of some of the felspathic lavas, either by simple weathering, or by gaseous emanations, converts them from a hard to a soft clayey state, so that they no longer retain the smallest resemblance to rocks cooled

* Journ. Sci. of vol. xv. p. 177.

† Voy. dans la Campanie, tome i. p. 201.

‡ Mr. Forbes, Edin. Journ. of Sci., No. xviii., Oct. 1828.

down from a state of fusion. The exhalations of sulphuretted hydrogen and muriatic acid, which are disengaged continually from the Solfatara, also produce curious changes on the trachyte of that nearly extinct volcano: the rock is bleached, and becomes porous, fissile, and honeycombed, till at length it crumbles into a white siliceous powder.* Numerous globular concretions, composed of concentric laminæ, are also formed by the same vapours in this decomposed rock.†

Vesuvian minerals. — A great variety of minerals are found in the lavas of Vesuvius and Somma: augite, leucite, felspar, mica, olivine, and sulphur, are most abundant. It is an extraordinary fact, that, in an area of three square miles round Vesuvius, a greater number of simple minerals have been found than in any spot of the same dimensions on the surface of the globe. Häuy enumerated only 380 species of simple minerals as known to him; and no less than eighty-two had been found on Vesuvius and in the tuffs on the flanks of Somma before the end of the year 1828.‡ Many of these are peculiar to that locality. Some mineralogists have conjectured that the greater part of these were not of Vesuvian origin, but thrown up in fragments from some older formation, through which the gaseous explosions burst. But none of the older rocks in Italy, or elsewhere, contain such an assemblage of mineral products; and the hypothesis seems to have been prompted by a disinclination to admit that, in times so recent in the earth's history, the laboratory of Nature could have been so prolific in the creation

* Daubeny on Volcanos, p. 169.

† Scrope, Geol. Trans., second series, vol. ii. p. 346.

‡ Monticelli and Covelli, Prodom. della Mineral. Vesuv.

of new and rare compounds. Had Vesuvius been a volcano of high antiquity, formed when Nature

> Wanton'd as in her prime, and played at will
> Her virgin fancies,

it would have been readily admitted that these, or a much greater variety of substances, had been sublimed in the crevices of lava, just as several new earthy and metallic compounds are known to have been produced by fumeroles, since the eruption of 1822.

Mass enveloping Herculaneum and Pompeii.—In addition to the ejections which fall on the cone, and that much greater mass which finds its way gradually to the neighbouring sea, there is a third portion, often of no inconsiderable thickness, composed of alluviums, spread over the valleys and plains at small distances from the volcano. Aqueous vapours are evolved copiously from volcanic craters during eruptions, and often for a long time subsequently to the discharge of scoriæ and lava: these vapours are condensed in the cold atmosphere surrounding the high volcanic peak, and heavy rains are thus caused. The floods thus occasioned sweep along the impalpable dust and light scoriæ, till a current of mud is produced, which is called, in Campania, "lava d'acqua," and is often more dreaded than an igneous stream (lava di fuoco), from the greater velocity with which it moves. So late as the 27th of October, 1822, one of these alluviums descended the cone of Vesuvius, and, after overspreading much cultivated soil, flowed suddenly into the villages of St. Sebastian and Massa, where, filling the streets and interior of some of the houses, it suffocated seven persons. It will therefore happen very frequently that,

towards the base of a volcanic cone, alternations will be found of lava, alluvium, and showers of ashes.

To which of these two latter divisions the mass enveloping Herculaneum and Pompeii should be referred, has been a question of the keenest controversy; but the discussion might have been shortened, if the combatants had reflected that, whether volcanic sand and ashes were conveyed to the towns by running water, or through the air, during an eruption, the interior of buildings, so long as the roofs remain entire, together with all underground vaults and cellars, could be filled only by an *alluvium*. We learn from history, that a heavy shower of sand, pumice, and lapilli, sufficiently great to render Pompeii and Herculaneum uninhabitable, fell for eight successive days and nights in the year 79, accompanied by violent rains. We ought, therefore, to find a very close resemblance between the strata covering these towns, and those composing the minor cones of the Phlegræan Fields, accumulated rapidly, like Monte Nuovo, during a continued shower of ejected matter; with this difference, however, that the strata incumbent on the cities would be horizontal, whereas those in the cones are highly inclined; and that large angular fragments of rock, which are thrown out near the vent, would be wanting at a distance where small lapilli only can be found. Accordingly, with these exceptions, no identity can be more perfect than the form and distribution of the matter at the base of Monte Nuovo, as laid open by the encroaching sea, and the appearance of the beds superimposed on Pompeii. That city is covered with numerous alternations of different horizontal beds of tuff and lapilli, for the most part thin, and subdivided into very fine layers. I observed the

following section near the amphitheatre, in November, 1828 — (descending series): —

	Feet.	Inches.
1. Black sparkling sand from the eruption of 1822, containing minute regularly formed crystals of augite and tourmaline, from .		2 to 3*
2. Vegetable mould	3	0
3. Brown incoherent tuff, full of *pisolitic globules* in layers, from half an inch to three inches in thickness	1	6
4. Small scoriæ and white lapilli . .	0	3
5. Brown earthy tuff, with numerous pisolitic globules	0	9
6. Brown earthy tuff, with lapilli divided into layers, ...	4	0
7. Layer of whitish lapilli . . .	0	1
8. Grey solid tuff	0	3
9. Pumice and white lapilli . . .	0	3
	10	4

Many of the ashes in these beds are vitrified, and harsh to the touch. Crystals of leucite, both fresh and farinaceous, have been found intermixed.† The depth of the bed of ashes above the houses is variable,

* The great eruption, in 1822, caused a covering only a few inches thick on Pompeii. Several feet are mentioned by Mr. Forbes. — Ed. Journ. of Science, No. xix. p. 131. Jan. 1829. But he must have measured in spots where it had drifted. The dust and ashes were five feet thick at the top of the crater, and decreased gradually to ten inches at Torre del Annunziata. The size and weight of the ejected fragments diminished very regularly in the same continuous stratum, as the distance from the centre of projection was greater.

† Forbes, ibid. p. 130.

but seldom exceeds twelve or fourteen feet, and it is said that the higher part of the amphitheatre always projected above the surface; though if this were the case, it seems inexplicable that the city should never have been discovered till the year 1750. It will be observed in the above section, that two of the brown, half-consolidated tuffs are filled with small pisolitic globules. This circumstance is not alluded to in the animated controversy which the Royal Academy of Naples maintained with one of their members, Signor Lippi, as to the origin of the strata incumbent on Pompeii. The mode of aggregation of these globules has been fully explained by Mr. Scrope, who saw them formed in great numbers, in 1822, by rain falling during the eruption on fine volcanic sand, and sometimes, also, produced like hail in the air, by the mutual attraction of the minutest particles of fine damp sand. There occurrence, therefore, agrees remarkably well with the account of heavy rain, and showers of sand and ashes, recorded in history.*

Lippi entitled his work, "Fù il fuoco o l' acqua che sotterò Pompei ed Ercolano?" † and he contended that neither were the two cities destroyed in the year 79, nor by a volcanic eruption, but purely by the agency of water charged with transported matter. His letters, wherein he endeavoured to dispense, as far as possible, with igneous agency, even at the foot of the volcano, were dedicated, with great propriety, to Werner, and afford an amusing illustration of the polemic style in which geological writers of that day indulged themselves. His arguments were partly of

* Scrope, Geol. Trans., second series, vol. ii. p. 346.

† Napoli, 1816.

an historical nature, derived from the silence of contemporary historians, respecting the fate of the cities which, as we have already stated, is most remarkable, and partly drawn from physical proofs. He pointed out with great clearness the resemblance of the tufaceous matter in the vaults and cellars at Herculaneum and Pompeii to aqueous alluviums, and its distinctness from ejections which had fallen through the air. Nothing, he observed, but moist pasty matter could have received the impression of a woman's breast, which was found in a vault at Pompeii, or have given the cast of a statue discovered in the theatre at Herculaneum. It was objected to him, that the heat of the tuff in Herculaneum and Pompeii was proved by the carbonization of the timber, corn, papyrus-rolls, and other vegetable substances there discovered: but Lippi replied with truth, that the papyri would have been burnt up, if they had come in contact with fire, and that their being only carbonized was a clear demonstration of their having been enveloped, like fossil wood, in a sediment deposited from water. The Academicians, in their report on his pamphlet, assert, that when the amphitheatre was first cleared out, the matter was arranged on the steps, in a succession of concave layers, accommodating themselves to the interior form of the building, just as snow would lie if it had fallen there. This observation is highly interesting, and points to the difference between the stratification of ashes in an open building, and of mud derived from the same in the interior of edifices and cellars. Nor ought we to call the allegation in question, because it could not be substantiated at the time of the controversy, after the matter had been all removed; although Lippi took advantage of this removal,

and met the argument of his antagonists by requiring them to prove the fact.

Pompeii not destroyed by lava.— There is decisive evidence that no stream of lava has ever reached Pompeii since it was first built, although the foundations of the town stand upon the old leucitic lava of Somma; several streams of which, with tuff interposed, have been cut through in excavations. At Herculaneum the case is different, although the substance which fills the interior of the houses and the vaults must have been introduced in a state of mud like that found in similar situations in Pompeii; yet the superincumbent mass differs wholly in composition and thickness. Herculaneum was situated several miles nearer to the volcano, and has, therefore, been always more exposed to be covered, not only by showers of ashes, but by alluviums and streams of lava. Accordingly, masses of both have accumulated on each other above the city, to a depth of nowhere less than 70, and in many places of 112 feet.*

The tuff which envelopes the buildings consists of comminuted volcanic ashes, mixed with pumice. A mask imbedded in this matrix has left a cast, the sharpness of which was compared by Hamilton to those in plaster of Paris; nor was the mask in the least degree scorched, as if it had been imbedded in heated matter. This tuff is porous; and, when first excavated, is soft and easily worked, but acquires a considerable degree of induration on exposure to the air. Above this lowest stratum is placed, according to Hamilton, "the matter of six eruptions," each separated from the other by veins of good soil. In these

* Hamilton, Observ. on Mount Vesuvius, p. 94. London, 1774.

soils Lippi states that he collected a considerable number of land shells — an observation which is no doubt correct; for many snails burrow in soft soils, and some Italian species descend, when they hybernate, to the depth of five feet and more from the surface. Della Torre also informs us that there is in one part of this superimposed mass a bed of true siliceous lava (*lava di pietra dura*); and, as no such current is believed to have flowed till near one thousand years after the destruction of Herculaneum, we must conclude, that the origin of a large part of the covering of Herculaneum was long subsequent to the first inhumation of the place. That city, at well as Pompeii, was a seaport Herculaneum is still very near the shore, but a tract of land, a mile in length, intervenes between the borders of the Bay of Naples and Pompeii. In both cases the gain of land is due to the filling up of the bed of the sea with volcanic matter, and not to elevation by earthquakes, for there has been no change in the relative level of land and sea. Pompeii stood on a slight eminence composed of the lavas of the ancient Vesuvius, and flights of steps led down to the water's edge. The lowermost of these steps are said to be still on an exact level with the sea.

Condition and contents of the buried cities.— After these observations on the nature of the strata enveloping and surrounding the cities, we may proceed to consider their internal condition and contents, so far at least as they offer facts of geological interest. Notwithstanding the much greater depth at which Herculaneum was buried, it was discovered before Pompeii, by the accidental circumstance of a well being sunk, in 1713, which came right down upon the theatre, where the statues of Hercules and Cleopatra were soon

found. Whether this city or Pompeii, both of them founded by Greek colonies, was the most considerable, is not yet determined; but both are mentioned by ancient authors as among the seven most flourishing cities in Campania. The walls of Pompeii were three miles in circumference; but we have, as yet, no certain knowledge of the dimensions of Herculaneum. In the latter place the theatre alone is open for inspection; the Forum, Temple of Jupiter, and other buildings, having been filled up with rubbish as the workmen proceeded, owing to the difficulty of removing it from so great a depth below ground. Even the theatre is only seen by torchlight, and the most interesting information, perhaps, which the geologist obtains there, is the continual formation of stalactite in the galleries cut through the tuff; for there is a constant percolation of water charged with carbonate of lime mixed with a small portion of magnesia. Such mineral waters must, in the course of time, create great changes in many rocks; especially in lavas, the pores of which they may fill with calcareous spar, so as to convert them into amygdaloids. Some geologists, therefore, are unreasonable when they expect that volcanic rocks of remote eras should accord precisely with those of modern date; since it is obvious that many of those produced in our own time will not long retain the same aspect and internal composition.

Both at Herculaneum and Pompeii, temples have been found with inscriptions commemorating the rebuilding of the edifices after they had been thrown down by an earthquake.* This earthquake happened in the reign of Nero, sixteen years before the cities

* Swinburne and Lalande. Paderni, Phil. Trans. 1758, vol. l. p. 619.

were overwhelmed. In Pompeii, one fourth of which is now laid open to the day, both the public and private buildings bear testimony to the catastrophe. The walls are rent, and in many places traversed by fissures still open. Columns are lying on the ground only half hewn from huge blocks of travertin, and the temple for which they were designed is seen half repaired. In some few places the pavement had sunk in, but in general it was undisturbed, consisting of large irregular flags of lava joined neatly together, in which the carriage wheels have often worn ruts an inch and a half deep. In the wider streets, the ruts are numerous and irregular; in the narrower, there are only two, one on each side, which are very conspicuous. It is impossible not to look with some interest even on these ruts, which were worn by chariot wheels more than seventeen centuries ago; and, independently of their antiquity, it is remarkable to see such deep incisions so continuous in a stone of great hardness.

Small number of skeletons.— A very small number of skeletons have been discovered in either city; and it is clear that most of the inhabitants not only found time to escape, but also to carry with them the principal part of their valuable effects. In the barracks at Pompeii were the skeletons of two soldiers chained to the stocks, and in the vaults of a country-house in the suburbs were the skeletons of seventeen persons, who appear to have fled there to escape from the shower of ashes. They were found inclosed in an indurated tuff, and in this matrix was preserved a perfect cast of a woman, perhaps the mistress of the house, with an infant in her arms. Although her form was imprinted on the rock, nothing but the bones remained. To these a chain of gold was suspended, and on the fingers

of the skeleton were rings with jewels. Against the sides of the same vault was ranged a long line of earthen amphoræ.

The writings scribbled by the soldiers on the walls of their barracks, and the names of the owners of each house written over the doors, are still perfectly legible. The colours of fresco paintings on the stuccoed walls in the interior of buildings are almost as vivid as if they were just finished. There are public fountains decorated with shells laid out in patterns in the same fashion as those now seen in the town of Naples; and in the room of a painter, who was perhaps a naturalist, a large collection of shells was found, comprising a great variety of Mediterranean species, in as good a state of preservation as if they had remained for the same number of years in a museum. A comparison of these remains with those found so generally in a fossil state would not assist us in obtaining the least insight into the time required to produce a certain degree of decomposition or mineralization; for, although under favourable circumstances, much greater alteration might doubtless have been brought about in a shorter period, yet the example before us shows that an inhumation of seventeen centuries may sometimes effect nothing towards the reduction of shells to the state in which fossils are usually found.

The wooden beams in the houses at Herculaneum are black on the exterior, but when cleft open, they appear to be almost in the state of ordinary wood, and the progress made by the whole mass towards the state of lignite is scarcely appreciable. Some animal and vegetable substances of more perishable kinds have of course suffered much change and decay, yet the state of conservation of these is truly remarkable.

Fishing-nets are very abundant in both cities, often quite entire; and their number at Pompeii is the more interesting from the sea being now, as we stated, a mile distant. Linen has been found at Herculaneum, with the texture well defined; and in a fruiterer's shop in that city were discovered vessels full of almonds, chestnuts, walnuts, and fruit of the "carubiere," all distinctly recognizable from their shape. A loaf, also, still retaining its form, was found in a baker's shop, with his name stamped upon it. On the counter of an apothecary was a box of pills converted into a fine earthy substance; and by the side of it a small cylindrical roll, evidently prepared to be cut into pills. By the side of these was a jar containing medicinal herbs. In 1827, moist olives were found in a square glass case, and "caviare," or roe of a fish, in a state of wonderful preservation. An examination of these curious condiments has been published by Covelli, of Naples, and they are preserved hermetically sealed in the museum there.*

Papyri.—There is a marked difference in the condition and appearance of the animal and vegetable substances found in Pompeii and Herculaneum; those of Pompeii being penetrated by a grey pulverulent tuff, those in Herculaneum seeming to have been first enveloped by a paste which consolidated round them, and then allowed them to become slowly carbonized. Some of the rolls of papyrus at Pompeii still retain their form; but the writing, and indeed almost all the vegetable matter, appear to have vanished, and to have been replaced by volcanic tuff somewhat pulverulent. At Herculaneum the earthy matter has scarcely ever penetrated; and the vegetable substance of the papy-

* Mr. Forbes, Edin. Journ. of Sci., No. xix. p. 130, Jan. 1829.

rus has become a thin friable black matter, almost resembling in appearance the tinder which remains when stiff paper has been burnt, in which the letters may still be sometimes traced. The small bundles of papyri, composed of five or six rolls tied up together, had sometimes lain horizontally, and were pressed in that direction, but sometimes they had been placed in a vertical position. Small tickets were attached to each bundle, on which the title of the work was inscribed. In one case only have the sheets been found with writing on both sides of the pages. So numerous are the obliterations and corrections, that many must have been original manuscripts. The variety of handwritings is quite extraordinary: nearly all are written in Greek, but there are a few in Latin. They were almost all found in a suburban villa in the library of one private individual; and the titles of four hundred of those least injured, which have been read, are found to be unimportant works, but all entirely new, chiefly relating to music, rhetoric, and cookery. There are two volumes of Epicurus "On Nature," and the others are mostly by writers of the same school, only one fragment having been discovered, by an opponent of the Epicurean system, Chrysippus.*

Probability of future discoveries of MSS.— In the opinion of some antiquaries, not one hundredth part of the city has yet been explored; and the quarters hitherto cleared out, at a great expense, are those where there was the least probability of discovering

* In one of the manuscripts which was in the hands of the interpreters when I visited the museum, the author indulges in the speculation that all the Homeric personages were allegorical — that Agamemnon was the ether, Achilles the sun, Helen the earth, Paris the air, Hector the moon, &c.

manuscripts. As Italy could already boast her splendid Roman amphitheatres and Greek temples, it was a matter of secondary interest to add to their number those in the dark and dripping galleries of Herculaneum; and having so many of the masterpieces of ancient art, we could have dispensed with the inferior busts and statues which could alone have been expected to reward our researches in the ruins of a provincial town. But from the moment that it was ascertained that rolls of papyrus preserved in this city could still be deciphered, every exertion ought to have been steadily and exclusively directed towards the discovery of other libraries. Private dwellings should have been searched, before so much labour and expense were consumed in examining public edifices. A small portion of that zeal and enlightened spirit which prompted the late French and Tuscan expedition to Egypt might long ere this, in a country nearer home, have snatched from oblivion some of the lost works of the Augustan age, or of eminent Greek historians and philosophers. A single roll of papyrus might have disclosed more matter of intense interest than all that was ever written in hieroglyphics.*

Stabiæ.—Besides the cities already mentioned, Stabiæ, a small town about six miles from Vesuvius,

* During my stay at Naples, in 1828, the Neapolitan government, after having discontinued operations for many years, cleared out a small portion of Herculaneum, near the sea, where the covering was least thick. After this expense had been incurred, it was discovered that the whole of the ground had been previously examined, near a century before, by the French Prince d'Elbœuf, who had removed every thing of value! Such is the want of system with which operations have always been, and still are, carried on here, that we may expect similar blunders to be made continually.

and near the site of the modern Castel-a-Mare (see map of volcanic district of Naples), was overwhelmed during the eruption of 79. Pliny mentions that, when his uncle was there, he was obliged to make his escape, so great was the quantity of falling stones and ashes. In the ruins of this place, a few skeletons have been found buried in volcanic ejections, together with some antiquities of no great value, and rolls of papyrus, which like those of Pompeii, were illegible.

Torre del Greco overflowed by lava. — Of the towns hitherto mentioned, Herculaneum alone has been overflowed by a stream of melted matter; but this did not, as we have seen, enter or injure the buildings, which were previously enveloped or covered over with tuff. But burning torrents have often taken their course through the streets of Torre del Greco, and consumed or inclosed a large portion of the town in solid rock. It seems probable that the destruction of three thousand of its inhabitants, in 1631, which some accounts attribute to boiling water, was principally due to one of those alluvial floods which we before mentioned: but, in 1737, the lava itself flowed through the eastern side of the town, and afterwards reached the sea; and, in 1794, another current, rolling over the western side, filled the streets and houses, and killed more than four hundred persons. The main street is now quarried through this lava, which supplied building stones for new houses erected where others had been annihilated. The church was half buried in a rocky mass, but the upper portion served as the foundation of a new edifice.

The number of the population at present is estimated at fifteen thousand; and a satisfactory answer may readily be returned to those who inquire how the in-

habitants can be so "inattentive to the voice of time and the warnings of nature*," as to rebuild their dwellings on a spot so often devastated. No neighbouring site unoccupied by a town, or which would not be equally insecure, combines the same advantages of proximity to the capital, to the sea, and to the rich lands on the flanks of Vesuvius. If the present population were exiled, they would immediately be replaced by another, for the same reason that the Maremma of Tuscany and the Campagna di Roma will never be depopulated, although the malaria fever commits more havoc in a few years than the Vesuvian lavas in as many centuries. The district around Naples supplies one amongst innumerable examples, that those regions where the surface is most frequently renewed, and where the renovation is accompanied, at different intervals of time, by partial destruction of animal and vegetable life, may nevertheless be amongst the most habitable and delightful on our globe.

I have already made a similar remark when speaking of tracts where aqueous causes are now most active; and the observation applies as well to parts of the surface which are the abode of aquatic animals, as to those which support terrestrial species. The sloping sides of Vesuvius give nourishment to a vigorous and healthy population of about eighty thousand souls; and the surrounding hills and plains, together with several of the adjoining isles, owe the fertility of their soil to matter ejected by prior eruptions. Had the fundamental limestone of the Apennines remained uncovered throughout the whole area, the country could not have sustained a twentieth part of its present inhabitants. This will be apparent to every geologist who has

* Sir H. Davy, Consolations in Travel, p. 66.

marked the change in the agricultural character of the soil the moment he has passed the utmost boundary of the volcanic ejections, as when, for example, at the distance of about seven miles from Vesuvius, he leaves the plain and ascends the declivity of the Sorrentine Hills.

Concluding remarks. — Yet, favoured as this region has been by Nature from time immemorial, the signs of the changes imprinted on it during the period that it has served as the habitation of man may appear in after-ages to indicate a series of unparalleled disasters. Let us suppose that at some future time the Mediterranean should form a gulf of the great ocean, and that the waves and tidal current should encroach on the shores of Campania, as it now advances upon the eastern coast of England; the geologist will then behold the towns already buried, and many more which will evidently be entombed hereafter, laid open in the steep cliffs, where he will discover buildings superimposed above each other, with thick intervening strata of tuff or lava — some unscathed by fire, like those of Herculaneum and Pompeii; others half melted down, as in Torre del Greco; and many shattered and thrown about in strange confusion, as in Tripergola, beneath Monte Nuovo. Among the ruins will be seen skeletons of men, and impressions of the human form stamped in solid rocks of tuff. Nor will the signs of earthquakes be wanting. The pavement of part of the Domitian Way, and the Temple of the Nymphs, submerged at high tide, will be uncovered at low water, the columns remaining erect and uninjured. Other temples which had once sunk down, like that of Serapis, will be found to have been upraised again by subsequent movements. If they who study these

phenomena, and speculate on their causes, assume that there were periods when the laws of Nature or the whole course of natural events differed greatly from those observed in their own time, they will scarcely hesitate to refer the wonderful monuments in question to those primeval ages. When they consider the numerous proofs of reiterated catastrophes to which the region was subject, they may, perhaps, commiserate the unhappy fate of beings condemned to inhabit a planet during its nascent and chaotic state, and feel grateful that their favoured race has escaped such scenes of anarchy and misrule.

Yet what was the real condition of Campania during those years of dire convulsion? "A climate where heaven's breath smells sweet and wooingly — a vigorous and luxuriant nature unparalleled in its productions — a coast which was once the fairy land of poets, and the favourite retreat of great men. Even the tyrants of the creation loved this alluring region, spared it, adorned it, lived in it, died in it." * The inhabitants, indeed, have enjoyed no immunity from the calamities which are the lot of mankind; but the principal evils which they have suffered must be attributed to moral, not to physical, causes — to disastrous events over which man might have exercised a control, rather than to the inevitable catastrophes which result from subterranean agency. When Spartacus encamped his army of ten thousand gladiators in the old extinct crater of Vesuvius, the volcano was more justly a subject of terror to Campania, than it has ever been since the rekindling of its fires.

* Forsyth's Italy, vol. ii.

CHAPTER XIII.

ETNA.

External physiognomy of Etna — Lateral cones — Their successive obliteration — Early eruptions — Monti Rossi in 1669 — Towns overflowed by lava — Part of Catania overflowed — Mode of advance of a current of lava — Subterranean caverns — Marine strata at base of Etna — Val del Bove not an ancient crater — Its scenery — Form, composition, and origin of the dikes — Linear direction of cones formed in 1811 and 1819 — Lavas and breccias — Flood produced by the melting of snow by lava — Glacier covered by a lava stream — Val del Bove how formed — Structure and origin of the cone of Etna — Whether the inclined sheets of lava were originally horizontal — Antiquity of Etna — Whether signs of diluvial waves are observable on Etna.

External physiognomy of Etna.— AFTER Vesuvius, our most authentic records relate to Etna, which rises near the sea in solitary grandeur to the height of nearly eleven thousand feet.* The base of the cone is almost circular, and eighty-seven English miles in circumfer-

* In 1815, Captain Smyth ascertained, trigonometrically, that the height of Etna was 10,874 feet. The Catanians, disappointed that their mountain had lost nearly 2000 feet of the height assigned to it by Recupero, refused to acquiesce in the decision. Afterwards, in 1824, Sir J. Herschel, not being aware of Captain Smyth's conclusions, determined by careful barometrical measurement, that the height was 10,872½ feet. This singular agreement of results so differently obtained was spoken of by Herschel as "a happy accident;" but Dr. Wollaston remarked that "it was one of those accidents which would not have happened to two fools."

ence; but if we include the whole district over which its lavas extend, the circuit is probably twice that extent.

Divided into three regions. — The cone is divided by nature into three distinct zones, called the *fertile*, the *woody*, and the *desert* regions. The first of these, comprising the delightful country around the skirts of the mountain, is well cultivated, thickly inhabited, and covered with olives, vines, corn, fruit-trees, and aromatic herbs. Higher up, the woody region encircles the mountain — an extensive forest, six or seven miles in width, affording pasturage for numerous flocks. The trees are of various species, the chestnut, oak, and pine being most luxuriant; while in some tracts are groves of cork and beech. Above the forest is the desert region, a waste of black lava and scoriæ; where, on a kind of plain, rises the cone to the height of about eleven hundred feet, from which sulphureous vapours are continually evolved. The most grand and original feature in the physiognomy of Etna is the multitude of minor cones which are distributed over its flanks, and which are most abundant in the woody region. These, although they appear but trifling irregularities when viewed from a distance as subordinate parts of so imposing and colossal a mountain, would, nevertheless, be deemed hills of considerable altitude in almost any other region.

Cones produced by lateral eruptions. — Without enumerating numerous monticules of ashes thrown out at different points, there are about eighty of these secondary volcanos, of considerable dimensions; fifty-two on the west and north, and twenty-seven on the east side of Etna. One of the largest, called Monte Minardo, near Bronte, is upwards of 700 feet in height,

and a double hill near Nicolosi, called Monti Rossi, formed in 1669, is 450 feet high, and the base two miles in circumference; so that it somewhat exceeds in size Monte Nuovo, before described. Yet it ranks only as a cone of the second magnitude amongst those produced by the lateral eruptions of Etna. On looking down from the lower borders of the desert region, these volcanos present us with one of the most delightful and characteristic scenes in Europe. They afford every variety of height and size, and are arranged in beautiful and picturesque groups. However uniform they may appear when seen from the sea, or the plains below, nothing can be more diversified than their shape when we look from above into their craters, one side of which is generally broken down. There are, indeed, few objects in nature more picturesque than a wooded volcanic crater. The cones situated in the higher parts of the forest zone are chiefly clothed with lofty pines; while those at a lower elevation are adorned with chestnuts, oaks, beech, and holm.

Successive obliteration of these cones.—The history of the eruptions of Etna, imperfect and interrupted as it is, affords us, nevertheless, much insight into the manner in which the whole mountain has successively attained its present magnitude and internal structure. The principal cone has more than once fallen in and been reproduced. In 1444 it was 320 feet high, and fell in after the earthquakes of 1537. In the year 1693, when a violent earthquake shook the whole of Sicily, and killed sixty thousand persons, the cone lost so much of its height, says Boccone, that it could not be seen from several places in Valdemone, from which it was before visible. The greater number of eruptions happen either from the great crater, or from lateral

openings in the desert region. When hills are thrown up in the middle zone, and project beyond the general level, they gradually lose their height during subsequent eruptions; for when lava runs down from the upper parts of the mountain, and encounters any of these hills, the stream is divided, and flows round them so as to elevate the gently sloping grounds from which they rise. In this manner a deduction is often made at once of twenty or thirty feet, or even more, from their height. Thus, one of the minor cones, called Monte Peluso, was diminished in altitude by a great lava stream which encircled it in 1444; and another current has recently taken the same course — yet this hill still remains four or five hundred feet high.

There is a cone called Monte Nucilla, near Nicolosi, round the base of which several successive currents have flowed, and showers of ashes have fallen, since the time of history, till at last, during an eruption in 1536, the surrounding plain was so raised, that the top of the cone alone was left projecting above the general level. Monte Nero, situated above the Grotta dell' Capre, was in 1766 almost submerged by a current; and Monte Capreolo afforded, in the year 1669, a curious example of one of the last stages of obliteration: for a lava stream, descending on a high ridge which had been built up by the continued superposition of successive lavas, flowed directly into the crater, and nearly filled it. The lava, therefore, of each new lateral cone tends to detract from the relative height of lower cones above their base: so that the flanks of Etna, sloping with a gentle inclination, envelop in succession a great multitude of minor volcanos, while new ones spring up from time to time.

Early eruptions of Etna.— Etna appears to have been in activity from the earliest times of tradition; for Diodorus Siculus mentions an eruption which caused a district to be deserted by the Sicani before the Trojan war. Thucydides informs us, that in the sixth year of the Peloponnesian war, or in the spring of the year 425 B. C., a lava stream ravaged the environs of Catania, and this, he says, was the third eruption which had happened in Sicily since the colonization of that island by the Greeks.* The second of the three eruptions alluded to by the historian took place in the year 475 B. C., and was that so poetically described by Pindar, two years afterwards, in his first Pythian ode: —

> *κιων*
> *Δ' ουρανια συνεχει*
> *Νιφοεσσ' Αιτνα, παντετες*
> *Χιονος οξειας τιθηνα.*

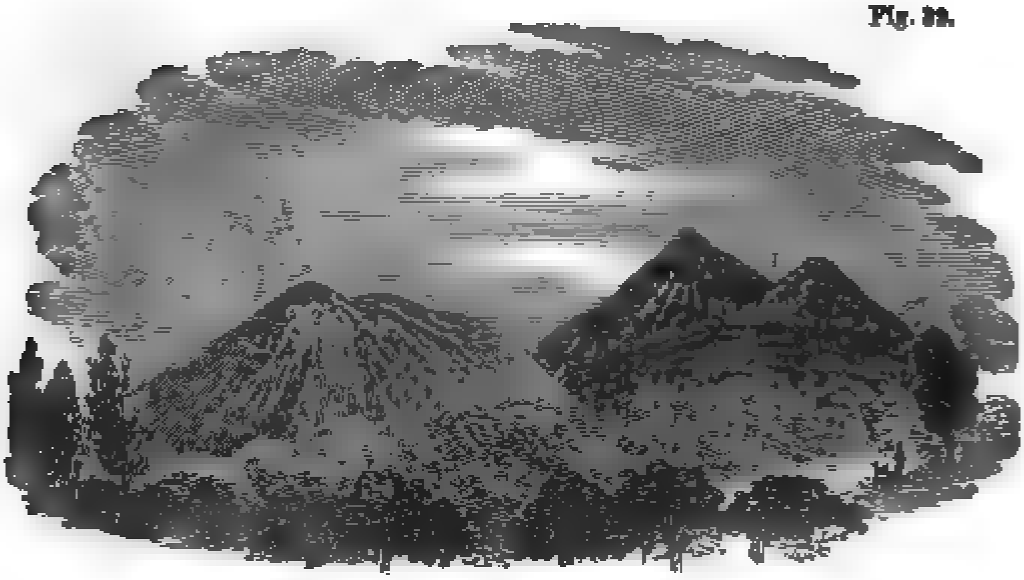
In these and the seven verses which follow, a graphic description is given of Etna, such as it appeared five centuries before the Christian era, and such as it has been seen when in eruption in modern times. The poet is only making a passing allusion to the Sicilian volcano, as the mountain under which Typhœus lay buried, yet by a few touches of his master hand every striking feature of the scene has been faithfully pourtrayed. We are told of "the snowy Etna, the pillar of heaven,— the nurse of everlasting frost, in whose deep caverns lie concealed the fountains of unapproachable fire — a stream of eddying smoke by day — a bright and ruddy flame by night; and burning rocks rolled down with loud uproar into the sea."

* Book iii., at the end.

Eruption of 1669 — *Monti Rossi formed.* — The great eruption which happened in the year 1669 is the first which claims particular attention. An earthquake had levelled to the ground all the houses in Nicolosi, a town situated near the lower margin of the woody region, about twenty miles from the summit of Etna, and ten from the sea at Catania. Two gulfs then opened near that town, from whence sand and scoriæ were thrown up in such quantity, that, in the course of three or four months, a double cone was formed, called Monti Rossi, about 450 feet high. But the most extraordinary phenomenon occurred at the commencement of the convulsion in the plain of S. Lio. A fissure six feet broad, and of unknown depth, opened with a loud crash, and ran in a somewhat tortuous course to within a mile of the summit of Etna. Its direction was from north to south, and its length twelve miles. It emitted a most vivid light. Five other parallel fissures of considerable length afterwards opened one after the other, and emitted smoke, and gave out bellowing sounds which were heard at the distance of forty miles. This case seems to present the geologist with an illustration of the manner in which those continuous dikes of vertical porphyry were formed, which are seen to traverse some of the older lavas of Etna; for the light emitted from the great rent of S. Lio appears to indicate that the fissure was filled to a certain height with incandescent lava, probably to the height of an orifice not far distant from Monti Rossi, which at that time opened and poured out a lava current. When the melted matter in such a rent has cooled, it must become a solid wall or dike, intersecting the older rocks of which the mountain is composed; similar rents have been observed during subsequent

eruptions, as in 1832, when they ran in all directions from the centre of the volcano. It has been justly

Fig. [illegible].



Minor cones on the flanks of Etna.

1, Monti Rossi, near Nicolosi, formed in 1669.
2, Vampoluso? *

remarked by M. Elie de Beaumont, that such star-shaped fractures may indicate a slight upheaval of the whole of Etna. They may be the signs of the stretching of the mass, which may thus be raised gradually by a force from below.†

The lava current of 1669, before alluded to, soon reached in its course a minor cone called Mompiliere, at the base of which it entered a subterranean grotto, communicating with a suite of those caverns which are so common in the lavas of Etna. Here it appears

* The hill which I have here introduced was called by my guide Vampolara, but the name given in the text is the nearest to this, which I find in Gemmellaro's Catalogue of Minor Cones.

† Mém. pour servir, &c. tom. iv. p. 116.

to have melted down some of the vaulted foundations of the hill, so that the whole of that cone became slightly depressed and traversed by numerous open fissures.

Part of Catania destroyed.— The lava, after overflowing fourteen towns and villages, some having a population of between three and four thousand inhabitants, arrived at length at the walls of Catania. These had been purposely raised to protect the city; but the burning flood accumulated till it rose to the top of the rampart, which was sixty feet in height, and then it fell in a fiery cascade and overwhelmed part of the city. The wall, however, was not thrown down, but was discovered long afterwards, by excavations made in the rock by the Prince of Biscari; so that the traveller may now see the solid lava curling over the top of the rampart as if still in the very act of falling.

This great current had performed a course of fifteen miles before it entered the sea, where it was still six hundred yards broad, and forty feet deep. It covered some territories in the environs of Catania, which had never before been visited by the lavas of Etna. While moving on, its surface was in general a mass of solid rock; and its mode of advancing, as is usual with lava streams, was by the occasional fissuring of the solid walls. A gentleman of Catania, named Papp lardo, desiring to secure the city from the approach of the threatening torrent, went out with a party of fifty men whom he had dressed in skins to protect them from the heat, and armed with iron crows and hooks. They broke open one of the solid walls which flanked the current near Belpasso, and immediately forth issued a rivulet of melted matter which took the direction of Paternò; but the inhabitants of that town, being

alarmed for their safety, took up arms and put a stop to further operations.*

As another illustration of the solidity of the walls of an advancing lava stream, I may mention an adventure related by Recupero, who, in 1766, had ascended a small hill formed of ancient volcanic matter, to behold the slow and gradual approach of a fiery current, two miles and a half broad; when suddenly two small threads of liquid matter issuing from a crevice detached themselves from the main stream, and ran rapidly towards the hill. He and his guide had just time to escape, when they saw the hill, which was fifty feet in height, surrounded, and in a quarter of an hour melted down into the burning mass, so as to flow on with it.

But it must not be supposed that this complete fusion of rocky matter coming in contact with lava is of universal, or even common, occurrence. It probably happens when fresh portions of incandescent matter comes successively in contact with fusible materials. In many of the dikes which intersect the tuffs and lavas of Etna, there is scarcely any perceptible alteration effected by heat on the edges of the horizontal beds, in contact with the vertical and more crystalline mass. On the site of Mompiliere, one of the towns overflowed in the great eruption above described, an excavation was made in 1704; and by immense labour the workmen reached, at the depth of thirty-five feet, the gate of the principal church, where there were three statues, held in high veneration. One of these, together with a bell, some money, and other articles, were extracted in a good state of perservation from beneath a great arch formed by the lava. It seems very extraordinary

* Ferrara, Descriz. dell' Etna, p. 108.

that any works of art, not encased with tuff, like those in Herculaneum, should have escaped fusion in hollow spaces left open in this lava current, which was so hot at Catania eight years after it entered the town, that it was impossible to hold the hand in some of the crevices.

Subterranean caverns on Etna. — Mention was made of the entrance of a lava stream into a subterranean grotto, whereby the foundations of a hill were partially undermined. Such underground passages are among the most curious features on Etna, and appear to have been produced by the hardening of the lava, during the escape of great volumes of elastic fluids, which are often discharged for many days in succession, after the crisis of the eruption is over. Near Nicolosi, not far from Monti Rossi, one of these great openings may be seen, called the Fossa della Palomba, 625 feet in circumference at its mouth, and seventy-eight deep. After reaching the bottom of this, we enter another dark cavity, and then others in succession, sometimes descending precipices by means of ladders. At length the vaults terminate in a great gallery ninety feet long, and from fifteen to fifty broad, beyond which there is still a passage, never yet explored; so that the extent of these caverns remains unknown.* The walls and roofs of these great vaults are composed of rough and bristling scoriæ, of the most fantastic forms.

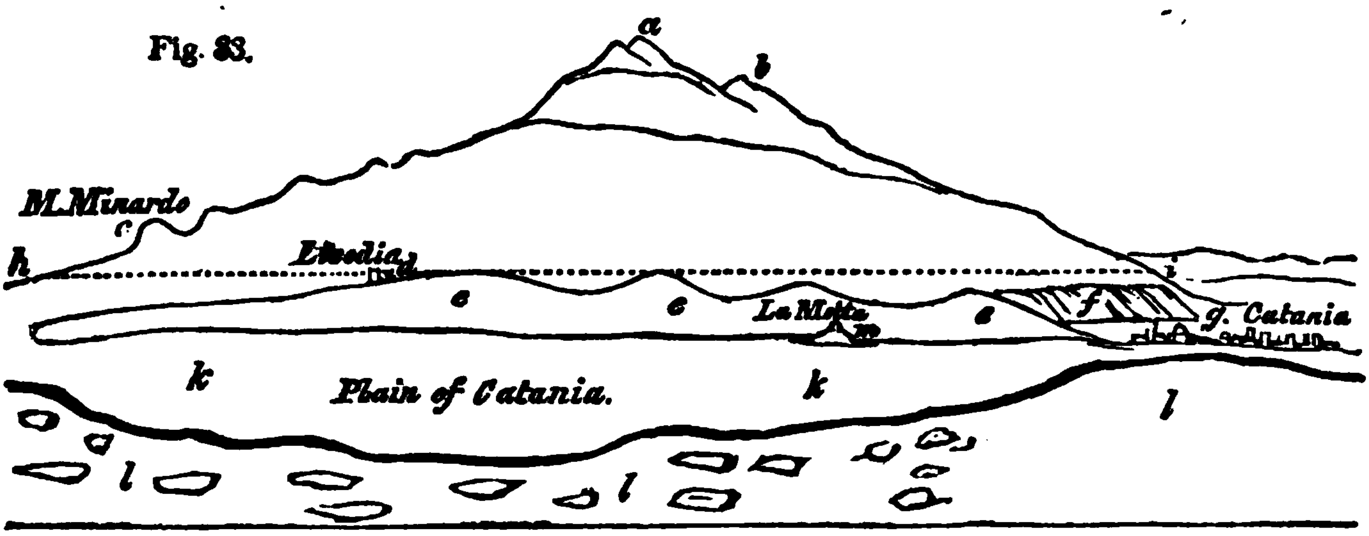
Marine strata at base of Etna.— If we skirt the fertile region at the base of Etna on its southern and eastern sides, we behold marine strata of clay, sand, and volcanic tuff, cropping out from beneath the modern lavas. The marine fossil shells occurring in these strata are all of them, or nearly all, identical

* Ferrara, Descriz. dell' Etna. Palermo, 1818.

with species now inhabiting the Mediterranean; and as they appear at the height of from 600 to 800 feet above the sea, near Catania, they clearly prove that there has been in this region, as in other parts of Sicily farther to the south, an upward movement of the ancient bed of the sea. It is fair, therefore, to infer that the whole mountain, with the exception of those parts which are of very modern origin, has participated in this upheaval.

If we view Etna from the south, we see the marine deposits above alluded to forming a low line of hills (*e*, *e*, fig. 33.) or a steep inland slope or cliff (*f*), as in the annexed drawing taken from the limestone platform of Primosole. It should be observed, however, in reference to this view, that the height of the volcanic cone is ten times greater than the hills at its base (*e*, *e*), although it appears less elevated, because

Fig. 33.



View of Etna from the summit of the limestone platform of Primosole.

a, Highest cone. *b*, Montagnuola.

c, Monte Minardo, with smaller lateral cones above.

d, Town of Licodia dei Monaci.

e, Marine formation called creta, argillaceous and sandy beds with a few shells, and associated volcanic rocks.

f, Escarpment of stratified subaqueous volcanic tuff, &c., north-west of Catania. *g*, Town of Catania.

h, *i*, Dotted line expressing the highest boundary along which the marine strata are occasionally seen. *k*, Plain of Catania.

l, Limestone platform of Primosole of the Newer Pliocene period.

m, La Motta di Catania.

the summit of the cone is ten or twelve times more distant from the plain of Catania than is Licodia.

The mountain is in general of a very symmetrical form, a flattened cone broken on its eastern side, by a deep valley called the Val del Bove, or in the provincial dialect of the peasants "Val di Bué," for here the herdsman

——"in reductâ valle *mugientium*
Prospectat errantes greges."

Dr. Buckland was, I believe, the first English geologist who examined this valley with attention, and I am indebted to him for having described it to me, before I visited Sicily, as more worthy of attention than any single spot in that island, or perhaps in Europe.

The Val del Bove commences near the summit of Etna, and descending into the woody region, is farther

Fig. 34.

Great valley on the east side of Etna.

a, Highest cone. *b*, Montagnuola.
c, Head of Val del Bove. *d*, *d*. Serre del Solfizio.
e, Village of Zaffarana on the lower border of the woody region.
f, One of the lateral cones. *g*, Monti Rossi.

continued on one side by a second and narrower valley, called the Val di Calanna. Below this another, named the Val di St. Giacomo, begins, — a long narrow ravine, which is prolonged to the neighbourhood of Zaffarana (*e*. Fig. 34.), on the confines of the fertile region. These natural incisions, into the side of the

volcano, are of such depth that they expose to view a great part of the structure of the entire mass, which in the Val del Bove, is laid open to the depth of from 3000 to above 4000 feet from the summit of Etna. The geologist thus enjoys an opportunity of ascertaining how far the internal conformation of the cone corresponds with what he might have anticipated as the result of that mode of increase which has been witnessed during the historical era.

Description of Plate VIII. — The accompanying view (Pl. VIII.) is part of a panoramic sketch which I made in November, 1828, and may assist the reader in comprehending some topographical details to be alluded to in the sequel, although it can convey no idea of the picturesque grandeur of the scene.

The great lava-currents of 1819 and 1811 are seen pouring down from the higher parts of the valley, overrunning the forests of the great plain, and rising up in the foreground on the left with a rugged surface, on which many hillocks and depressions appear, such as often characterize a lava-current immediately after its consolidation.

The small cone, No. 7., was formed in 1811, and was still smoking when I saw it in 1828. The other small volcano to the left, from which vapour is issuing, was, I believe, one of those formed in 1819.

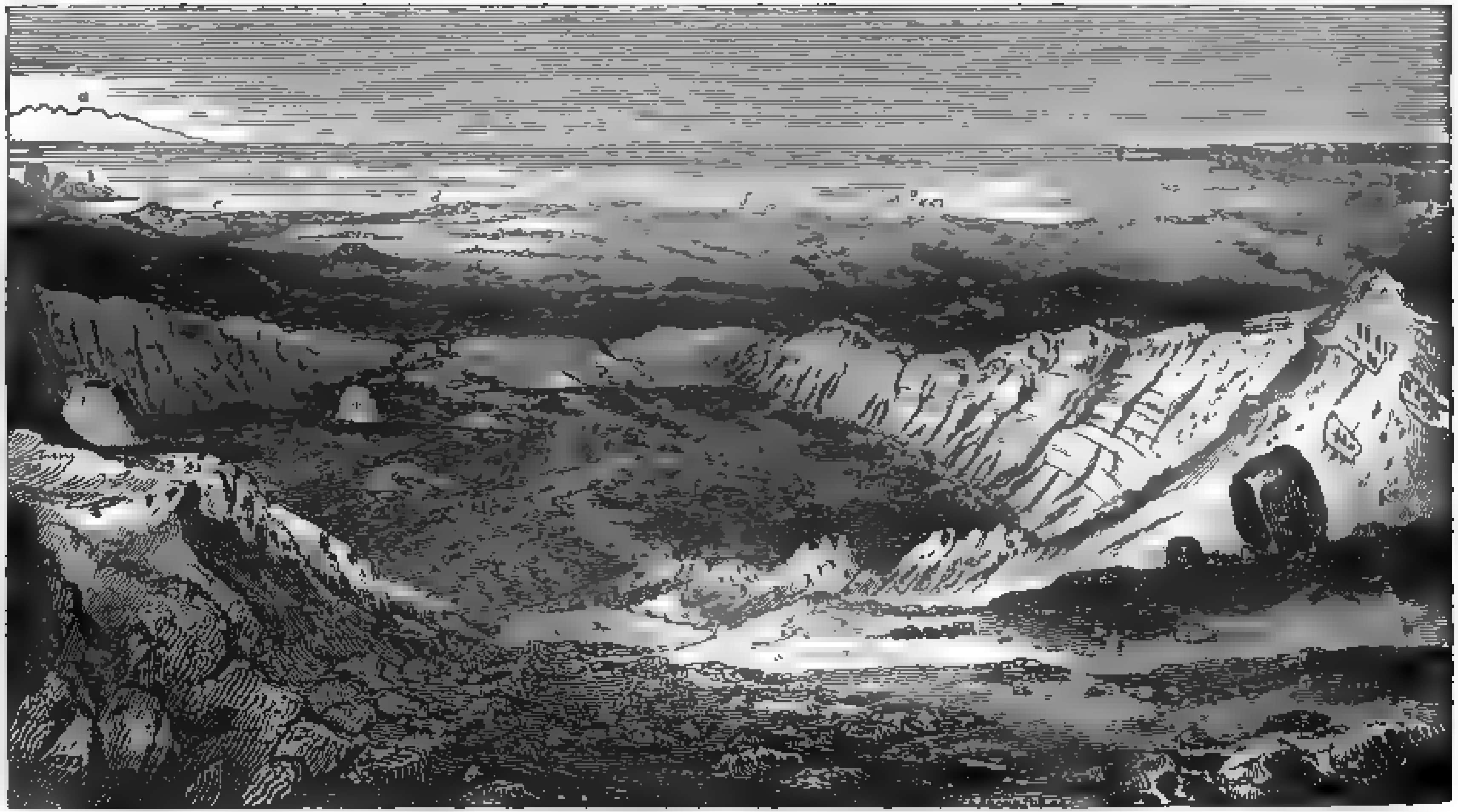
The following are the names of some of the other points indicated in the sketch :—

1, Montagnuola.	5, Finocchio.	9, Musara.
2, Torre del Filosofo.	6, Capra.	10, *Zocolaro*.
3, Highest cone.	7, Cone of 1811.	11, Rocca di Calanna.
4, Lepra.	8, Cima del Asino.	

Description of Plate IX.— The second view (Pl. IX.) represents the same valley as seen from above, or look-

VIEW LOOKING UP THE VAL DEL BOVE, ETNA.

PLATE IX.



VIEW OF VAL DEL BOVE, ETNA, AS SEEN FROM ABOVE, OR FROM CRATER OF 1819.

ing directly down the Val del Bove, from the summit of the principal crater formed in 1819.* I am unable to point out the precise spot which this crater would occupy in the view represented in Plate VIII.; but I conceive that it would appear in the face of the great precipice, near which the smoke issuing from the cone No. 7. is made to terminate. There are many ledges of rock on the face of that precipice where eruptions have occurred.

The circular form of the Val del Bove is well shown in this view. (Pl. IX.) To the right and left are the lofty precipices which form the southern and northern sides of the great valley, and which are intersected by dikes projecting in the manner afterwards to be described. In the distance appears the "fertile region" of Etna, extending like a great plain along the sea coast.

The spots particularly referred to in the plate are the following: —

a, Cape Spartivento, in Italy, of which the outline is seen in the distance.
b, The promontory of Taormino, on the Sicilian coast.
c, The river Alcantra.
d, The small village of Riposto.
f, The town of Aci Reale.
g, Cyclopian islands, or "Faraglioni," in the Bay of Trezza.
h, The great harbour of Syracuse.
k, The Lake of Lentini.
i, The city of Catania, near which is marked the course of the lava which flowed from the Monti Rossi in 1669, and destroyed part of the city.
l, To the left of the view is the crater of 1811, which is also shown at No. 7., in Plate VIII.
m, Rock of Musara, also seen at No. 9., in Plate VIII.
e, Valley of Calanna.

* This view is taken from a sketch made by Mr. James Bridges, corrected after comparison with several sketches of my own.

The Val del Bove is of truly magnificent dimensions, a vast amphitheatre four or five miles in diameter, surrounded by nearly vertical precipices, varying from 1000 to above 3000 feet in height, the loftiest being at the upper end, and the height gradually diminishing on both sides. The feature which first strikes the geologist as distinguishing the boundary cliffs of this valley, is the prodigious multitude of vertical dikes, which are seen in all directions traversing the volcanic beds. The circular form of this great chasm, and the occurrence of these countless dikes, amounting perhaps to several thousands in number, so forcibly recalled to my mind the phenomena of the Atrio del Cavallo, on Vesuvius, that I at first imagined that I had entered a vast crater, on a scale as far exceeding that of Somma as Etna surpasses Vesuvius in magnitude.

But I was soon undeceived when I had attentively explored the different sides of the great amphitheatre, in order to satisfy myself whether the semicircular wall of the Val del Bove had ever formed the boundary of a crater, and whether the beds had the same quâ-quâ-versal dip which is so beautifully exhibited in the escarpment of Somma. Had the supposed analogy between Somma and the Val del Bove held true, the tuffs and lavas at the head of the valley would have dipped to the west, those on the north side towards the north, and those on the southern side to the south. But such I did not find to be the inclination of the beds; they all dip towards the sea, or nearly east, as in the valleys of St. Giacomo and Calanna below.

Scenery of the Val del Bove.—Let the reader picture to himself a large amphitheatre, five miles in diameter, and surrounded on three sides by precipices

from to 2000 to 3000 feet in height. If he has beheld that most picturesque scene in the chain of the Pyrenees, the celebrated "cirque of Gavarnie," he may form some conception of the magnificent circle of precipitous rocks which inclose, on three sides, the great plain of the Val del Bove. This plain has been deluged by repeated streams of lava; and although it appears almost level, when viewed from a distance, it is, in fact, more uneven than the surface of the most tempestuous sea. Besides the minor irregularities of the lava, the valley is in one part interrupted by a ridge of rocks, two of which, Musara and Capra, are very prominent. It can hardly be said that they

——— "like giants stand
To sentinel enchanted land;"

for although, like the Trosachs, in the Highlands of Scotland, they are of gigantic dimensions, and appear almost isolated, as seen from many points, yet the stern and severe grandeur of the scenery which they adorn is not such as would be selected by a poet for a vale of enchantment. The character of the scene would accord far better with Milton's picture of the infernal world; and if we imagine ourselves to behold in motion, in the darkness of the night, one of those fiery currents which have so often traversed the great valley, we may well recall

——— "yon dreary plain, forlorn and wild,
The seat of desolation, void of light,
Save what the glimmering of these livid flames
Casts pale and dreadful."

The face of the precipices already mentioned is broken in the most picturesque manner by the vertical

walls of lava which traverse them. These masses usually stand out in relief, are exceedingly diversified in form, and of immense altitude. In the autumn, their black outline may often be seen relieved by clouds of fleecy vapour which settle behind them, and do not disperse until mid-day, continuing to fill the valley while the sun is shining on every other part of Sicily, and on the higher regions of Etna.

As soon as the vapours begin to rise, the changes of scene are varied in the highest degree, different rocks being unveiled and hidden by turns, and the summit of Etna often breaking through the clouds for a moment with its dazzling snows, and being then as suddenly withdrawn from the view.

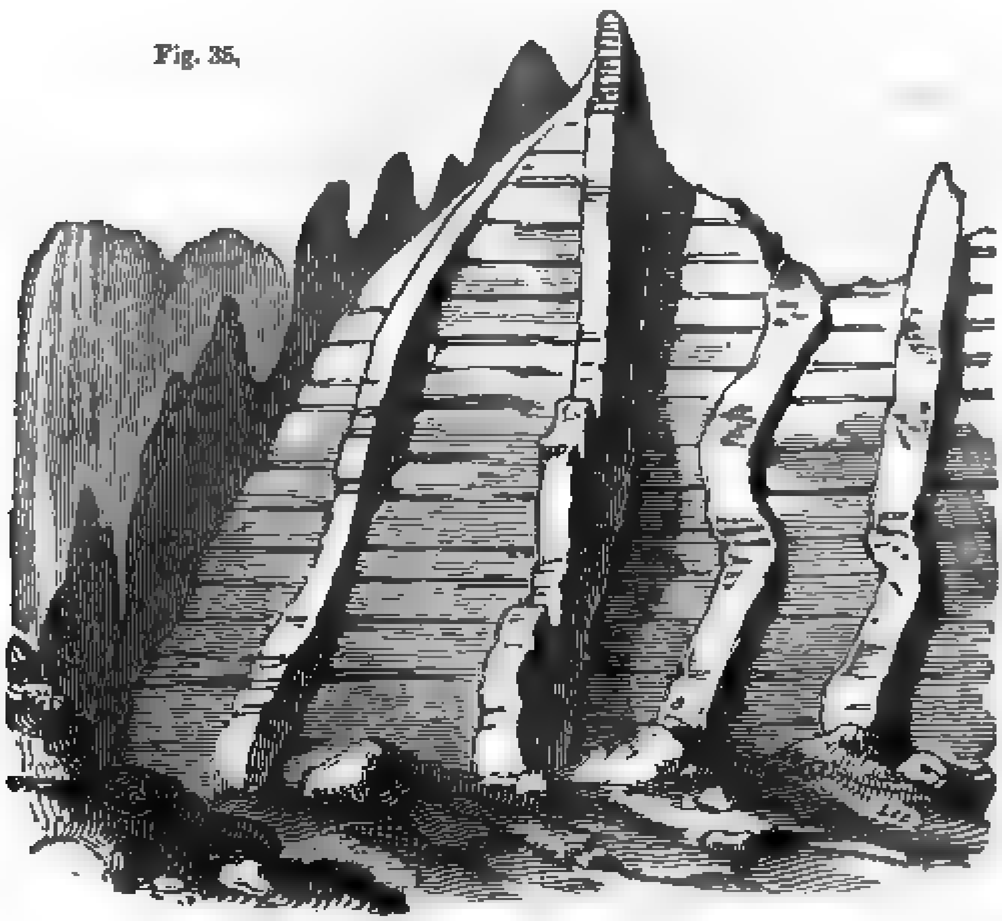
An unusual silence prevails; for there are no torrents dashing from the rocks, nor any movement of running water in this valley, such as may almost invariably be heard in mountainous regions. Every drop of water that falls from the heavens, or flows from the melting ice and snow, is instantly absorbed by the porous lava; and such is the dearth of springs, that the herdsman is compelled to supply his flocks, during the hot season, from stores of snow laid up in hollows of the mountain during winter.

The strips of green herbage and forest land, which have here and there escaped the burning lavas, serve, by contrast, to heighten the desolation of the scene. When I visited the valley, nine years after the eruption of 1819, I saw hundreds of trees, or rather the white skeletons of trees, on the borders of the black lava, the trunks and branches being all leafless, and deprived of their bark by the scorching heat emitted from the melted rock; an image recalling those beautiful lines: —

——— "As when heaven's fire
Hath scath'd the forest oaks, or mountain pines,
With singed top their stately growth, though bare,
Stands on the blasted heath.

Form, composition, and origin of the dikes.—But without indulging the imagination any longer in descriptions of scenery, I may observe, that the dikes before mentioned form unquestionably the most interesting geological phenomenon in the Val del Bove. Some of these are composed of trachyte, others of

Fig. 35.

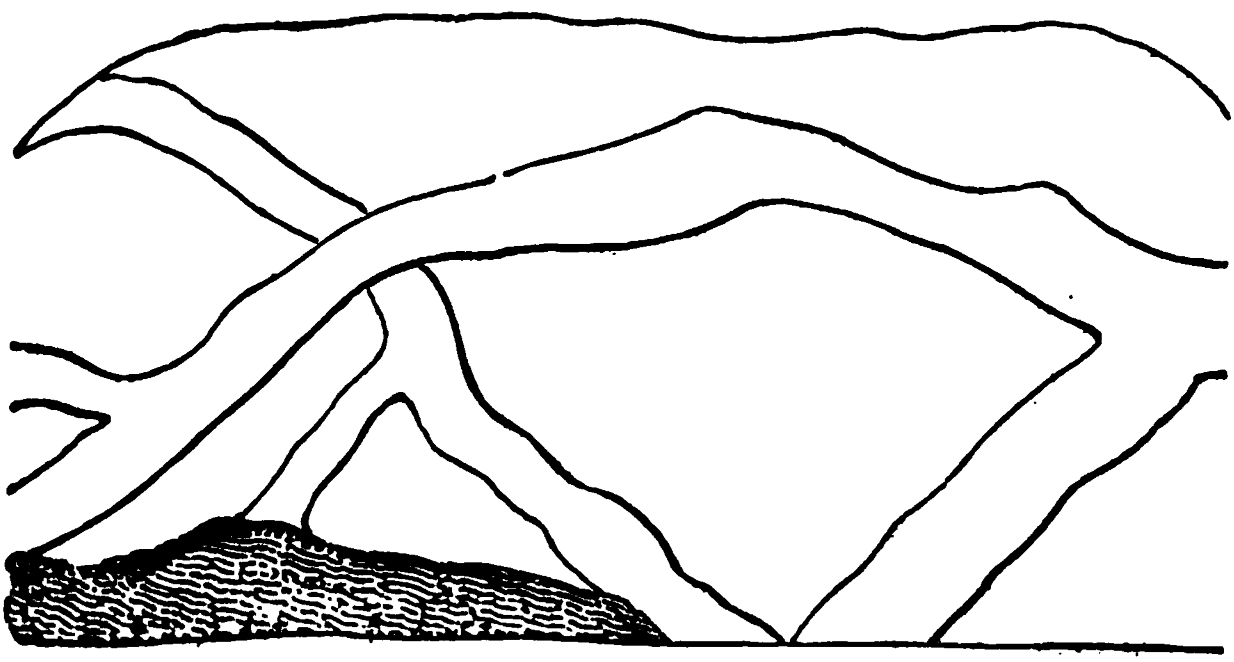


Dikes at the base of the Serre del Solfizio, Etna.

compact blue basalt with olivine. They vary in breadth from two to twenty feet and upwards, and

usually project from the face of the cliffs, as represented in the annexed drawing (Fig. 35). They consist of harder materials than the strata which they traverse, and therefore waste away less rapidly under the influence of that repeated congelation and thawing to which the rocks in this zone of Etna are exposed. The dikes are, for the most part, vertical, but sometimes they run in a tortuous course through the tuffs and breccias, as represented in Fig. 36. In the escarpment of Somma, where similar walls of lava cut through alternating beds of sand and scoriæ, a coating of coal-black rock, approaching in its nature and appearance to pitchstone, is seen at the contact of the dike with the intersected beds. I did not observe such parting layers at the junction of the Etnean dikes which I examined, but they may perhaps be discoverable.

Fig. 36.



Tortuous veins of lava, at Punto di Giumento, Etna.

The geographical position of these dikes is most interesting, as they are very numerous near the head of the Val del Bove, where the cones of 1811 and 1819

were thrown up, as also in that zone of the mountain where lateral eruptions are frequent; whereas, in the Valley of Calanna, which is below that parallel, and in a region where lateral eruptions are extremely rare, scarcely any dikes are seen, and none whatever still lower in the valley of St. Giacomo. This is precisely what we might have expected, if we consider the vertical fissures now filled with rock to have been the feeders of lateral cones, or, in other words, the channels which gave passage to the lava currents and scoriæ that have issued from vents in the forest zone. In other parts of Etna there may be numerous dikes at as low a level as the Valley of Calanna, because the line of lateral eruptions is not everywhere at the same height above the sea; but in the section above alluded to there appeared to me an obvious connection between the frequency of dikes and of lateral eruptions.

Some fissures may have been filled from above, but I did not see any which, by terminating downwards, gave proof of such an origin. Almost all the isolated masses in the Val del Bove, such as Capra, Musara, and others, are traversed by dikes, and may, perhaps, have partly owed their preservation to that circumstance, if at least the action of occasional floods has been one of the destroying causes in the Val del Bove; for there is nothing which affords so much protection to a mass of strata against the undermining action of running water as a perpendicular dike of hard rock.

In the accompanying drawing (Fig. 37.) the flowing of the lavas of 1811 and 1819, between the rocks Finochio, Capra, and Musara, is represented. The height of the two last mentioned isolated masses has been much diminished by the elevation of their base, caused by these currents. They may, perhaps, be the

Fig. 37.

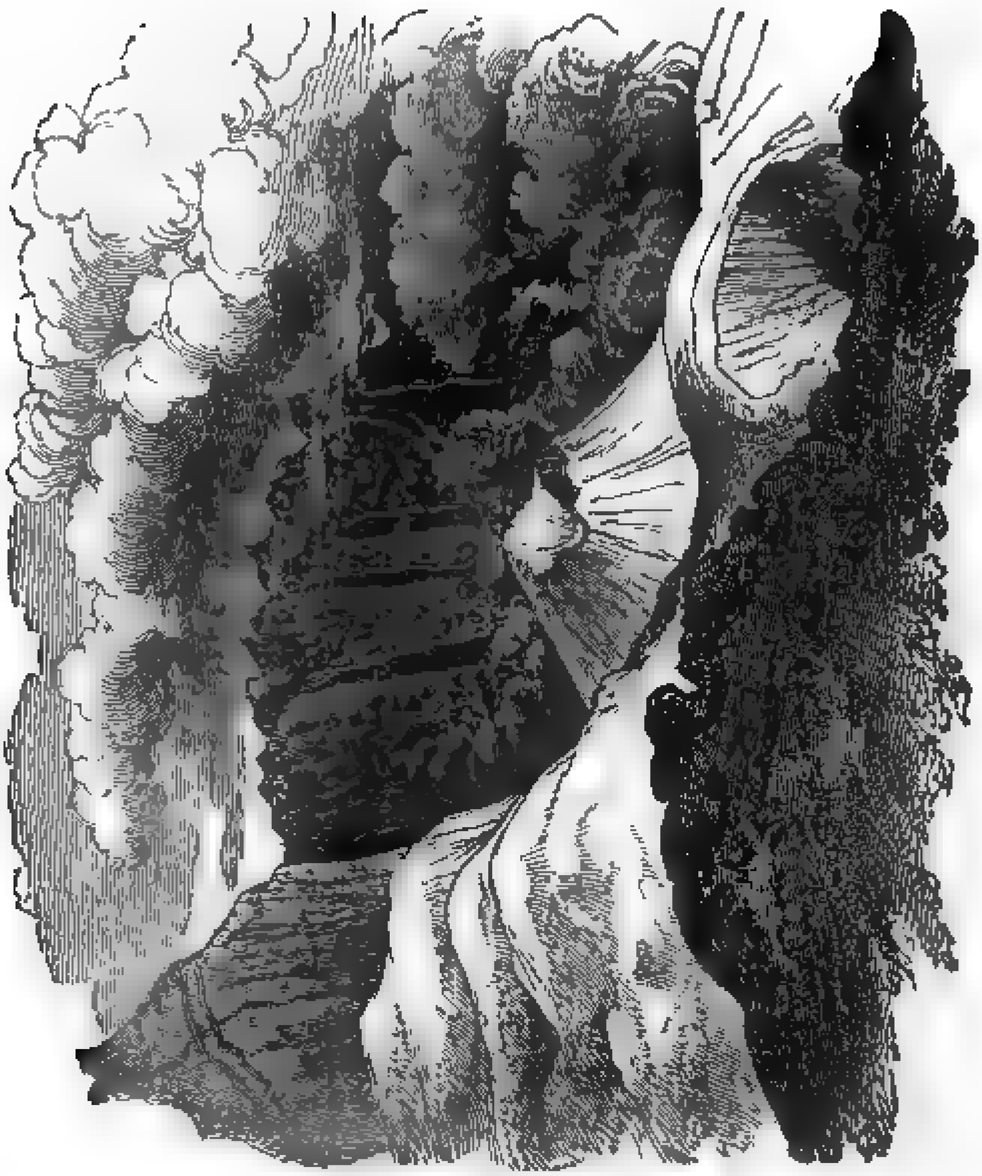
View of the rocks Finocchio, Capra, and Musara, Val del Bove.

remnants of lateral cones which existed before the Val del Bove was formed, and may hereafter be once more buried by the lavas that are now accumulating in the valley.

From no point of view are the dikes more conspicuous than from the summit of the highest cone of Etna; a view of some of them is given in the annexed drawing. (Fig. 38.)

Eruption of 1811.—I have alluded to the streams of lava which were poured forth in 1811 and 1819. Gemmellaro, who witnessed these eruptions, informs us that the great crater in 1811 first testified, by its loud detonations, that a column of lava had ascended to near the summit of the mountain. A violent shock was then felt, and a stream broke out from the side of the cone, at no great distance from its apex. Shortly after this had ceased to flow, a second stream burst forth at

Fig. 39.



*View from the summit of Etna into the Val del Bove.**

another opening, considerably below the first; then a third still lower, and so on till seven different issues had been thus successively formed, all lying upon the

* This drawing is part of a panoramic sketch which I made from the summit of the cone, December 1. 1828, when every part of Etna was free from clouds except the Val del Bove. The small cone, and the crater nearest the foreground, were among those formed during the eruptions of 1810 and 1811.

same straight line. It has been supposed that this line was a perpendicular rent in the internal framework of the mountain, which rent was probably not produced at one shock, but prolonged successively downwards, by the lateral pressure and intense heat of the internal column of lava, as it subsided by gradual discharge through each vent.*

Eruption of 1819.—In 1819 three large mouths or caverns opened very near those which were formed in the eruptions of 1811, from which flames, red-hot cinders, and sand, were thrown up with loud explosions. A few minutes afterwards another mouth opened below, from which flames and smoke issued; and finally a fifth, lower still, whence a torrent of lava, flowed, which spread itself with great velocity over the deep and broad valley called "Val del Bove." This stream flowed two miles in the first twenty-four hours, and nearly as far in the succeeding day and night. The three original mouths at length united into one large crater, and sent forth lava, as did the inferior apertures, so that an enormous torrent poured down the "Val del Bove." When it arrived at a vast and almost perpendicular precipice, at the head of the valley of Calanna, it poured over in a cascade, and, being hardened in its descent, made an inconceivable crash as it was dashed against the bottom. So immense was the column of dust raised by the abrasion of the tufaceous hill over which the hardened mass descended, that the Catanians were in great alarm, supposing a new eruption to have burst out in the woody region, exceeding in violence that near the summit of Etna.

* Scrope on Volcanos, p. 153.

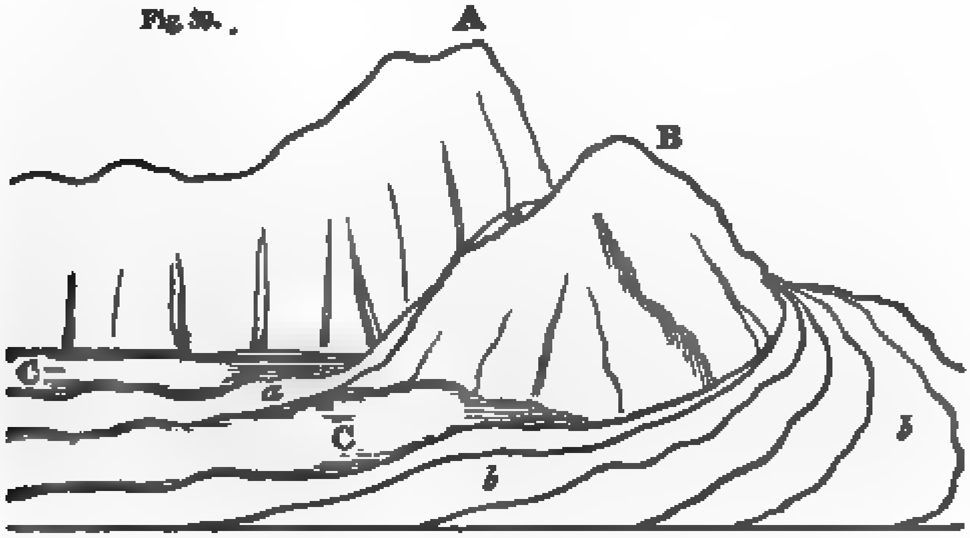
Mode of advance of the lava. — Of the cones thrown up during this eruption, not more than two are of sufficient magnitude to be numbered among those eighty which were before described as adorning the flanks of Etna. The surface of the lava which deluged the "Val del Bove" consists of rocky and *angular blocks*, tossed together in the utmost disorder. Nothing can be more rugged, or more unlike the smooth and even superficies which those who are unacquainted with volcanic countries may have pictured to themselves, in a mass of matter which had consolidated from a liquid state. Mr. Scrope observed this current in the year 1819, slowly advancing down a considerable slope, at the rate of about a yard an hour, nine months after its first emission. The lower stratum being arrested by the resistance of the ground, the upper or central part gradually protruded itself, and being unsupported, fell down. This in its turn was covered by a mass of more liquid lava, which swelled over it from above. The current had all the appearance of a huge heap of rough and large cinders rolling over and over upon itself by the effect of an extremely slow propulsion from behind. The contraction of the crust as it solidified, and the friction of the scoriform cakes against one another, produced a crackling sound. Within the crevices a dull red heat might be seen by night, and vapour issuing in considerable quantity was visible by day.*

It was stated that when the lava of 1819 arrived at the head of the Valley of Calanna, after flowing down the Val del Bove, it descended in a cascade. This stream, in fact, like many previous currents of lava which have flowed down successively from the

* Scrope on Volcanos, p. 102.

higher regions of Etna, was turned by a great promontory projecting from the southern side of the Val del Bove. This promontory consists of the hills called Zocolaro and Calanna, and of a ridge of inferior height which connects them. (See Fig. 39.)

Fig. 39.



A, Zocolaro. B, Monte di Calanna.
C, Plain at the head of the Valley of Calanna.
a, Lava of 1819 descending the precipice and flowing through the valley.
b, Lavas of 1811 and 1819 flowing round the hill of Calanna.

It happened in 1811 and 1819 that the flows of lava overtopped the ridge intervening between the hills of Zocolaro and Calanna, so that they fell in a cascade over a lofty precipice, and began to fill up the valley of Calanna. (*a*, Fig. 39.) Other portions of the same lava-current (*b*) flowed round the promontory, and they exhibit one of the peculiar characteristics of such streams, namely, that of becoming solid externally, even while yet in motion. Instead of thinning out gradually at their edges, their sides may often be compared to two rocky walls, which are sometimes inclined at an angle of between thirty and forty degrees. When such streams are turned from their course by a projecting rock, they move right onwards

in a new direction; and in the valley of Calanna a considerable space has thus been left between the steep sides of the lavas *b b*, so deflected, and the precipitous escarpment of Zocolaro, A, which bounds the plain C.

Lavas and Breccias. — In regard to the volcanic masses which are intersected by dikes in the Val del Bove, they consist in great part of greystone lavas, of an intermediate character between basalt and trachyte, and partly of porphyritic lava, resembling trachyte, but to which that name cannot, according to Von Buch and G. Rose, be in strictness applied, because the felspar belongs to the variety called Labradorite. There is great similarity in the composition of the ancient and modern lavas of Etna, both consisting of felspar, augite, olivine, and titaniferous iron. The alternating breccias are made up of scoriæ, sand, and angular blocks of lava. Many of these fragments may have been thrown out by volcanic explosions, which falling on the hardened surface of moving lava-currents, may have been carried to a considerable distance. It may also happen that when lava advances very slowly, in the manner of the flow of 1819, the angular masses resulting from the frequent breaking of the mass, as it rolls over upon itself, may produce these breccias. It is at least certain that the upper portion of the lava-currents of 1811 and 1819 now consist of angular masses to the depth of many yards. D'Aubuisson has compared the surface of one of the ancient lavas of Auvergne to that of a river suddenly frozen over by the stoppage of immense fragments of drift-ice, a description perfectly applicable to these modern Etnean flows. The thickness of the separate beds of conglomerate or breccia which are seen in the same vertical section is often extremely different, vary-

ing from 3 to nearly 50 feet, as I observed in the hill of Calanna.

Flood produced by the melting of snow by lava. — It is possible that some of the breccias or conglomerates may be referred to aqueous causes, as great floods occasionally sweep down the flanks of Etna, when eruptions take place in winter, and when the snows are melted by lava. It is true that running water in general exerts no power on Etna, the rain which falls being immediately imbibed by the porous lavas; so that, vast as is the extent of the mountain, it feeds only a few small rivulets, and these, even, are dry throughout the greater portion of the year. The enormous rounded boulders, therefore, of felspar-porphyry and basalt, a line of which can be traced from the sea, from near Giardini, by Mascali, and Zafarana, to the "Val del Bove," would offer a perplexing problem to the geologist, if history had not preserved the memorials of a tremendous flood which happened in this district in the year 1755. It appears that two streams of lava flowed in that year, on the 2d of March, from the highest crater: they were immediately precipitated upon an enormous mass of snow which then covered the whole mountain, and was extremely deep near the summit. The sudden melting of this frozen mass, by a fiery torrent three miles in length, produced a frightful inundation, which devastated the sides of the mountain for eight miles in length, and afterwards covered the lower flanks of Etna, where they were less steep, together with the plains near the sea, with great deposits of sand, scoriæ, and blocks of lava.

Many absurd stories circulated in Sicily respecting this event; such as that the water was boiling, and that it was vomited from the highest crater; that it was as

salt as the sea, and full of marine shells; but these were mere inventions, to which Recupero, although he relates them as tales of the mountaineers, seems to have attached rather too much importance.

Floods of considerable violence have also been produced on Etna by the fall of heavy rains, aided, probably, by the melting of snow. By this cause alone, in 1761, sixty of the inhabitants of Acicatena were killed, and many of their houses swept away.*

Glacier covered by a lava-stream.—A remarkable discovery was made on Etna in 1828 of a great mass of ice, preserved for many years, perhaps for centuries, from melting, by the singular accident of a current of red hot lava having flowed over it. The following are the facts in attestation of a phenomenon which must at first sight appear of so paradoxical a character. The extraordinary heat experienced in the South of Europe, during the summer and autumn of 1828, caused the supplies of snow and ice which had been preserved in the spring of that year, for the use of Catania and the adjoining parts of Sicily and the island of Malta, to fail entirely. Great distress was consequently felt for want of a commodity regarded in those countries as one of the necessaries of life rather than an article of luxury, and the abundance of which contributes in some of the larger cities to the salubrity of the water and the general health of the community. The magistrates of Catania applied to Signor M. Gemmellaro, in the hope that his local knowledge of Etna might enable him to point out some crevice or natural grotto on the mountain, where drift snow was still preserved. Nor were they disappointed; for he had long suspected that a small mass of perennial ice at

* Ferrara, Descriz. dell' Etna, p. 116.

the foot of the highest cone was part of a large and continuous glacier covered by a lava-current. Having procured a large body of workmen, he quarried into this ice, and proved the super-position of the lava for several hundred yards, so as completely to satisfy himself that nothing but the subsequent flowing of the lava over the ice could account for the position of the glacier. Unfortunately for the geologist, the ice was so extremely hard, and the excavation so expensive, that there is no probability of the operations being renewed.

On the first of December, 1828, I visited this spot, which is on the south-east side of the cone, and not far above the Casa Inglese; but the fresh snow had already nearly filled up the new opening, so that it had only the appearance of the mouth of a grotto. I do not, however, question the accuracy of the conclusion of Signor Gemmellaro, who, being well acquainted with all the appearances of drift snow in the fissures and cavities of Etna, had recognized, even before the late excavations, the peculiarity of the position of the ice in this locality. We may suppose that, at the commencement of the eruption, a deep mass of drift snow had been covered by volcanic sand showered down upon it before the descent of the lava. A dense stratum of this fine dust mixed with scoriæ is well known to be an extremely bad conductor of heat; and the shepherds in the higher regions of Etna are accustomed to provide water for their flocks during summer, by strewing a layer of volcanic sand a few inches thick over the snow, which effectually prevents the heat of the sun from penetrating.

Suppose the mass of snow to have been preserved from liquefaction until the lower part of the lava had

consolidated, we may then readily conceive that a glacier thus protected, at the height of ten thousand feet above the level of the sea, would endure as long as the snows of Mont Blanc, unless melted by volcanic heat from below. When I visited the great crater in the beginning of winter (December 1st, 1828), I found the crevices in the interior encrusted with thick ice, and in some cases hot vapours were actually streaming out between masses of ice and the rugged and steep walls of the crater.

After the discovery of Signor Gemmellaro, it would not be surprising to find in the cones of the Icelandic volcanos, which are covered for the most part with perpetual snow, repeated alternations of lava-streams and glaciers. We have, indeed, Lieutenant Kendall's authority for the fact that Deception Island, in New South Shetland, lat. 62° 55′ S., is principally composed of alternate layers of ashes and ice.*

Origin of the Val del Bove.—We cannot ascribe this valley to the action of running water; for if it had been excavated exclusively by that power, its depth would have increased in the descent; whereas, on the contrary, the precipices are most lofty at the upper extremity, and diminish gradually on approaching the lower region of the volcano.

Dr. Daubeny states, that during the eruption of Vesuvius in 1834, the mountain, and all the adjacent country was violently shaken on the night of August 24. At the same time, two small conical hillocks of volcanic matter which existed in the great crater disappeared. They do not seem to have been ejected, or blown into the air, but to have been actually swallowed up in some internal cavity.

* Journ. of Roy. Geograph. Soc. vol. i. p. 64.

It is recorded, as will be stated in the history of earthquakes, that in the year 1772 a great subsidence took place on Papandayang, the largest volcano in the island of Java, an extent of ground *fifteen miles in length, and six in breadth,* covered by no less than forty villages, was engulphed, and the cone lost 4000 feet of its height. So also the summit of Carguairazo, one of the loftiest of the Andes of Quito, fell in on the 19th July, 1698; and another mountain of still greater altitude in the same chain, called Capac Urcu, a short time before the conquest of America by the Spaniards.

Now we might imagine a similar event, or a series of subsidences to have formerly occurred on the eastern side of Etna, although such catastrophes have not been witnessed in modern times, or only on a very trifling scale. A narrow ravine, about a mile long, twenty feet wide, and from twenty to thirty-six in depth, has been formed, within the historical era, on the flanks of the volcano, near the town of Mascalucia; and a small circular tract, called the Cisterna, near the summit, sank down in the year 1792, to the depth of about forty feet, and left on all sides of the chasm a vertical section of the beds, exactly resembling those which are seen in the precipices of the Val del Bove. At some remote periods, therefore, we might suppose more extensive portions of the mountain to have fallen in during great earthquakes.

Structure and Origin of the Cone of Etna.— Our data for speculating on the manner in which the cone of Etna has acquired its present dimensions and internal structure are very imperfect, because it is on its eastern side only, in the Val del Bove, that we see a deep section exposed. Even here we obtain no insight

into the interior composition of the mountain beyond a depth of between three and four thousand feet below the base of that highest cone, which has been several times destroyed and renewed. The precipices seen at the head of the Val del Bove, in the escarpment called the Serre del Solfizio, exhibit merely the same series of alternating lavas and breccias, which descending with a general dip towards the sea, form the boundary cliffs of all other parts of the Val del Bove. If then we estimate the height of Etna at about 11,000 feet, we may say that we know from actual observation less than one half of its component materials, assuming it to extend downwards to the level of the sea; namely, first, the highest cone, which is about 1000 feet above its base; and, secondly, the alternations of lava, tuff, and volcanic breccia, which constitute the rocks between the Cisterna, near the base of the upper cone, and the foot of the precipices at the head of the Val del Bove. At the lowest point to which the vertical section extends, there are no signs of any approach to a termination of the purely volcanic mass, which may perhaps penetrate many thousand feet farther downwards. There is, indeed, a rock called Rocca Giannicola, near the foot of the great escarpment, which consists of a large mass between 150 and 200 feet wide, not divided into beds, and almost resembling granite in its structure, although agreeing very closely in mineral composition with the lavas of Etna in general.* This mass may doubtless be taken as a representative of those crystalline or plutonic formations which would be met with in abundance if we could descend to greater depths in the direction of the central axis of the mountain. For a

* Hoffman, Geognost. Beobachtungen, p. 701. Berlin, 1839.

great body of geological evidence leads us to conclude, that rocks of this class result from the consolidation, under great pressure of melted matter, which has risen up and filled rents and chasms, such, for example, as may communicate with the principal and minor vents of eruption in a volcano like Etna.

But, if we speculate on the nature of the formations which the lava may have pierced in its way upwards, we may fairly presume that a portion of these consist of marine tertiary rocks, like those of the neighbouring Val di Noto, or those which skirt the borders of the Etnean cone, on its southern and eastern sides. Etna may, in fact, have been at first an insular volcano, raising its summit but slightly above the level of the sea, but we have no grounds for concluding that any of the beds exposed in the deep section of the Val del Bove, have formed a part of such a marine accumulation. On the contrary, all the usual signs of subaqueous origin are wanting; and even if we believe the foundations of the mountain to have been laid in the sea, we could not expect this portion to be made visible in sections which only proceed downwards from the summit through one half the thickness of the mountain, especially as the highest points attained by the tertiary strata in other parts of Sicily very rarely exceed 3000 feet above the sea.

On the eastern and southern base of Etna, a marine deposit, already alluded to, is traced up to the height of 800 or 1000 feet, before it becomes concealed beneath that covering of modern lavas which is continually extending its limits during successive eruptions, and prevents us from ascertaining how much higher the marine strata may ascend. As the imbedded shells belong almost entirely to species now inhabiting the

Mediterranean, it is evident that there has been here an upheaval of the region at the base of Etna at a very modern period. It is fair, therefore, to infer that the volcanic nucleus of the mountain, partly perhaps of submarine, and partly of subaërial origin, participated in this movement, and was carried up bodily. Now, in proportion as a cone gains height by such a movement, combined with the cumulative effects of eruptions, throwing out matter successively from one or more central vents, the hydrostatic pressure of the columns of lava augment with their increasing height, until the time arrives when the flanks of the cone can no longer resist the increased pressure; and from that period they give way more readily, lateral outbursts becoming more frequent. Hence, independently of any local expansion of the fractured volcanic mass, those general causes by which the modern tertiary strata of a great part of Sicily have been raised to the height of several thousand feet above their original level, would tend naturally to render the discharge of lava and scoriæ from the summit of Etna less copious, and the lateral discharge greater.

If, then, a conical or dome-shaped mass of volcanic materials was accumulated to the height of 4000, or perhaps 7000 feet, before the upward movement began, or what is much more probable, during the continuance of the upward movement, that ancient mass would not be buried under the products of newer eruptions, because these last would then be poured out chiefly at a lower level.

Since I visited Etna in 1828, M. de Beaumont has published a most valuable memoir on the structure and origin of that mountain, which he examined in 1834;*

* Mém. pour servir, &c. tom. iv. Paris, 1838.

and an excellent description of it has also appeared in the posthumous work of Hoffman.*

In M. de Beaumont's essay, in which he has explained his views with uncommon perspicuity and talent, he maintains that all the alternating stony and fragmentary beds, more than 3000 feet thick, which are exposed in the Val del Bove, were formed originally on a surface so nearly flat that the slope never exceeded three degrees. From this horizontal position they were at length heaved up suddenly (d'un seul coup) into a great mountain, to which no important additions have since been made. Prior to this upthrow, a platform is supposed to have existed above the level of the sea, in which various fissures opened; and from these melted matter was spread forth again and again, which spread itself around in thin sheets of uniform thickness. From the same rents issued showers of scoriæ and fragmentary matter, which were spread out so as to form equally uniform and horizontal beds, intervening between the sheets of lava. But although, by the continued repetition of these operations, a vast pile of volcanic matter, 4000 feet or more in thickness, was built up precisely in that region where Etna now rises, and to which nothing similar was produced elsewhere in Sicily, still we are told that Etna was not yet a mountain. No hypothetical diagram has been given to help us to conceive how this great mass of materials of supramarine origin could have been disposed of in horizontal beds, so as not to constitute an eminence towering far above the rest of Sicily; but it is assumed that a powerful force from below at length burst suddenly through the horizontal formation, uplifted it to a considerable height, and caused the beds to be, in many

* Geognost. Beobachtungen, &c. Berlin, 1839.

places, highly inclined. This elevatory force was not all expended on a single central point, as Von Buch has imagined in the case of Palma, Teneriffe, or Somma, but rather followed for a short distance a linear direction.*

Among other objections that may be advanced against the theory above proposed, I may mention, first, that the increasing number of dikes as we approach the head of the Val del Bove, or the middle of Etna, and the great thickness of lava, scoriæ, and conglomerates in that region, imply that the great centre of eruption was always where it now is, or nearly at the same point, and there must, therefore, have been a tendency, from the beginning, to a conical or dome-shaped arrangement in the ejected materials. Secondly, were we to admit a great number of separate points of eruption, scattered over a plain or platform, there must then have been a great number of cones thrown up over these different vents, and these hills, some of which would probably be as lofty as those now seen on the flanks of Etna, or from 300 to 750 feet in height, would break the continuity of the sheets of lava, while they would become gradually enveloped by them. The ejected materials, moreover, would slope at a high angle on the sides of these cones, and where they fell on the surrounding plain, would form strata thicker near the base of each cone than at a distance.

What then are the facts, it will be asked, to account for which this hypothesis of original horizontality, followed by a single and sudden effort of upheaval, has been invented? It is remarked by M. de Beaumont, "that, in many parts of the boundary precipices of

* De Beaumont, Mém. pour servir, &c. tom. iv. pp. 187, 188.

the Val del Bove, the sheets of lava are inclined at an angle of from 25° to 30°; sometimes less than half this amount; while, in other places, as near the head of the valley, they are almost horizontal, yet there is a uniformity in the thickness both of the stony and fragmentary beds in which these various slopes are observable. The alternating sheets also of lava, and beds of scoriæ, are not only of considerable length but great breadth, whereas modern streams of lava, which are known to have descended a slope of 30°, 20°, or even 10°, form narrow stripes, never accumulate to a great thickness, nor acquire a compact texture, and their thickness varies with every variation of steepness in the declivity down which they flow."

That the uniformity ascribed to the alternating beds in the Val del Bove hold true throughout large areas, I do not deny, yet it is no easy matter to feel certain of the continuity of the same identical beds for hundreds of yards, much less for miles, when their number in the vertical series is so great, and when all are so similar to each other in mineral composition, and, above all, when they are cut through by countless dikes, many of them several yards wide, and often ramifying and crossing each other. If the line of section passes through a stream of lava obliquely, or nearly in the direction of its original course, we may find it continuous for miles, although its breadth, or continuity, if cut through transversely, may be slight.

It may, however, be conceded as most probable that the greater part of these beds were originally less inclined, some of them much less so than now; and their subsequent disturbance is quite consistent with the doctrine before explained of the successive fracturing,

distention, and upheaval of a great cone during a series of eruptions.

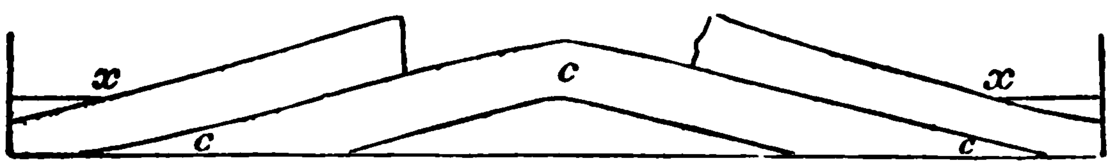
We know not how large a quantity of modern lava may have been poured into the bottom of the Val del Bove, yet we perceive that eruptions breaking forth near the centre of Etna have already made some progress in filling up this great hollow. Even within the memory of persons now living, the rocks of Musara and Capra have, as before stated, lost much of their height and picturesque grandeur by the piling up of recent lavas round their base (see Fig. 37. p. 226.), and the great chasm has intercepted many streams which would otherwise have deluged the fertile region below, as has happened on the side of Catania. The volcanic forces are now labouring, therefore, to repair the breach which subsidence has caused on one side of the great cone; and unless their energy should decline, or a new sinking take place, they may in time efface this inequality. In that event, the restored portion will always be unconformable to the more ancient part, yet it will consist, like it, of alternating beds of lava, scoriæ, and conglomerates, which, with all their irregularities, will have a general slope from the centre and summit of Etna towards the sea. They may also be intersected by dikes or fissures, like those formed in the year 1669 in the plain of San Lio. (See p. 211.)

I shall conclude, then, by remarking that I conceive the general inclination of the alternating stony and fragmentary beds of the Val del Bove, from the axis of Etna towards its circumference or base, and the greater thickness of the volcanic pile as we approach the central parts of the mountain, to be due to the preponderance of eruptions from that centre. These gave rise, from the first, to a dome shaped mass, which

has ever since been increasing in height and area, being fractured again and again by the expansive force of vapours, and the severed parts made to cohere together more firmly after the solidification of the lava with which every open fissure and chasm has been filled. At the same time the cone may have gained a portion of its height by the elevatory effect of such dislocating movements, and the sheets of lava may have acquired in some places a greater, in others a less, inclination than that which at first belonged to them.

But had the mountain been due solely, or even principally, to upheaval, its structure would have resembled that which geologists have so often recognized in certain dome-shaped hills, or elevated regions, which all consider as having been thrust up by a force from below. In this case there is often an elliptical cavity at the summit, due partly to the fracture of the upraised rocks, but still more to aqueous denudation, as they rose out of the sea. This central cavity, or valley, exposes to view the subjacent formation *c*, Fig. 40.,

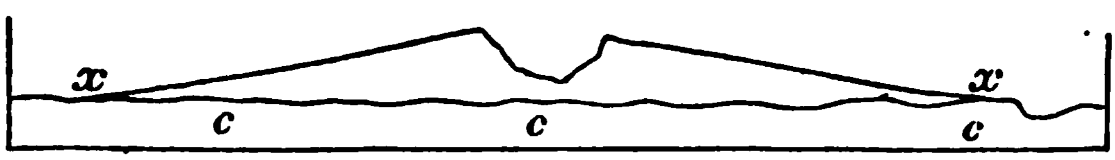
Fig. 40.



Non-volcanic portuberance and valley of elevation.

and the incumbent mass dips away on all sides from the axis, but has no tendency to thin out near the base of the dome, or at *x*, *x*; whereas at this point the volcanic mass terminates (see Fig. 41.) and allows

Fig. 41.



Volcanic mountain and crater.

the fundamental rock *c* to appear at the surface. In the last diagram the more ordinary case is represented of a great hollow or crater at the summit of the volcanic cone, but instead of this, we have seen that in the case of Etna there is a deep lateral depression, called the Val del Bove, the upper part of which approaches near to the central axis, and the origin of which we have attributed to subsidence.

Antiquity of the cone of Etna.—It was before remarked that confined notions in regard to the quantity of past time have tended, more than any other prepossessions, to retard the progress of sound theoretical views in geology; * the inadequacy of our conceptions of the earth's antiquity having cramped the freedom of our speculations in this science, very much in the same way as a belief in the existence of a vaulted firmament once retarded the progress of astronomy. It was not until Descartes assumed the indefinite extent of the celestial spaces, and removed the supposed boundaries of the universe, that just opinions began to be entertained of the relative distances of the heavenly bodies; and until we habituate ourselves to contemplate the possibility of an indefinite lapse of ages having been comprised within each of the modern periods of the earth's history, we shall be in danger of forming most erroneous and partial views in geology.

Mode of computing the age of volcanos.—If history had bequeathed to us a faithful record of the eruptions of Etna, and a hundred other of the principal active volcanos of the globe, during the last three thousand years,—if we had an exact account of the volume of lava and matter ejected during that period, and the times of their production,—we might, perhaps,

* Vol. I. p. 113.

be able to form a correct estimate of the average rate of the growth of a volcanic cone. For we might obtain a mean result from the comparison of the eruptions of so great a number of vents, however irregular might be the development of the igneous action in any one of them, if contemplated singly during a brief period.

It would be necessary to balance protracted periods of inaction against the occasional outburst of paroxysmal explosions. Sometimes we should have evidence of a repose of seventeen centuries, like that which was interposed in Ischia, between the end of the fourth century, B. C., and the beginning of the fourteenth century of our era.* Occasionally, a tremendous eruption, like that of Jurullo, would be recorded, giving rise, at once, to a considerable mountain.

If we desire to approximate to the age of a cone such as Etna, we ought first to obtain some data in regard to the thickness of matter which has been added during the historical era, and then endeavour to estimate the time required for the accumulation of such alternating lavas and beds of sand and scoriæ as are superimposed upon each other in the Val del Bove; afterwards we should try to deduce, from observations on other volcanos, the more or less rapid increase of burning mountains in all the different stages of their growth.

Mode of increase of volcanos analogous to that of exogenous trees.—There is a considerable analogy between the mode of increase of a volcanic cone and that of trees of *exogenous* growth. These trees augment, both in height and diameter, by the successive appli-

* See p. 158.

cation externally of cone upon cone of new ligneous matter; so that if we make a transverse section near the base of the trunk, we intersect a much greater number of layers than nearer to the summit. When branches occasionally shoot out from the trunk, they first pierce the bark, and then, after growing to a certain size, if they chance to be broken off, they may become inclosed in the body of the tree, as it augments in size, forming knots in the wood, which are themselves composed of layers of ligneous matter, cone within cone.

In like manner, a volcanic mountain, as we have seen, consists of a succession of conical masses enveloping others, while lateral cones, having a similar internal structure, often project, in the first instance, like branches from the surface of the main cone, and then becoming buried again, are hidden like the knots of a tree.

We can ascertain the age of an oak or pine by counting the number of concentric rings of annual growth seen in a transverse section near the base, so that we may know the date at which the seedling began to vegetate. The Baobab-tree of Senegal (*Adansonia digitata*) is supposed to exceed almost any other in longevity; Adanson inferred that one which he measured, and found to be thirty feet in diameter, had attained the age of 5150 years. Having made an incision to a certain depth, he first counted three hundred rings of annual growth, and observed what thickness the tree had gained in that period. The average rate of growth of younger trees, of the same species, was then ascertained, and the calculation made according to a supposed mean rate of increase. De Candolle considers it not improbable that the celebrated Tax-

odium of Chapultepec, in Mexico (*Cupressus disticha* Linn.), which is 117 feet in circumference, may be still more aged.*

It is, however, impossible, until more data are collected respecting the average intensity of the volcanic action, to make any thing like an approximation to the age of a cone like Etna; because, in this case, the successive envelopes of lava and scoriæ are not continuous, like the layers of wood in a tree, and afford us no definite measure of time. Each conical envelope is made up of a great number of distinct lava-currents and showers of sand and scoriæ, differing in quantity, and which may have been accumulated in unequal periods of time. Yet we cannot fail to form the most exalted conception of the antiquity of this mountain, when we consider that its base is about ninety miles in circumference; so that it would require ninety flows of lava, each a mile in breadth at their termination, to raise the present foot of the volcano as much as the average height of one lava-current.

There are no records within the historical era which lead to the opinion that the altitude of Etna has materially varied within the last two thousand years. Of the eighty most conspicuous minor cones which adorn its flanks, only one of the largest, Monti Rossi, has been produced within the times of authentic history. Even this hill, thrown up in the year 1669, although 450 feet in height, only ranks as a cone of second magnitude. Monte Minardo, near Bronte, rises, even now, to the height of 750 feet, although its base has been elevated by more modern lavas and ejections. The dimensions of these larger cones appear to bear testimony to *paroxysms* of volcanic activity, after which

* On the Longevity of Trees, Bibliot. Univ., May, 1831.

we may conclude, from analogy, that the fires of Etna remained dormant for many years — since nearly a century of rest has sometimes followed a violent eruption in the historical era. It must also be remembered, that of the small number of eruptions which occur in a century, one only is estimated to issue from the summit of Etna for every two that proceed from the sides. Nor do all the lateral eruptions give rise to such cones as would be reckoned amongst the smallest of the eighty hills above enumerated; some of them produce merely insignificant monticules, which are soon afterwards buried by showers of ashes.

How many years then must we not suppose to have been expended in the formation of the eighty cones? It is difficult to imagine that a fourth part of them have originated during the last thirty centuries. But if we conjecture the whole of them to have been formed in twelve thousand years, how inconsiderable an era would this portion of time constitute in the history of the volcano! If we could strip off from Etna all the lateral monticules now visible, together with the lavas and scoriæ that have been poured out from them, and from the highest crater, during the period of their growth, the diminution of the entire mass would be extremely slight! Etna might lose, perhaps, several miles in diameter at its base, and some hundreds of feet in elevation; but it would still be the loftiest of Sicilian mountains, studded with other cones, which would be recalled, as it were, into existence by the removal of the rocks under which they are now buried.

There seems nothing in the deep sections of the Val del Bove to indicate that the lava-currents of remote periods were greater in volume than those of

modern times; and there are abundant proofs that the countless beds of solid rock and scoriæ were accumulated, as now, in succession. On the grounds, therefore, already explained, we must infer that a mass so many thousand feet in thickness must have required an immense series of ages anterior to our historical periods for its growth; yet the whole must be regarded as the product of a modern portion of the tertiary epoch. Such, at least, is the conclusion that seems to follow from geological data, which show that the oldest parts of the mountain, if not of posterior date to the marine strata around its base, were at least of coeval origin.

Whether signs of diluvial waves are observable on Etna. — Some geologists contend, that the sudden elevation of large continents from beneath the waters of the sea have again and again produced waves which have swept over vast regions of the earth, and left enormous rolled blocks strewed upon the surface.* That there are signs of local floods of extreme violence, on various parts of the surface of the dry land, is incontrovertible, and I have endeavoured to point out causes which must for ever continue to give rise to such phenomena; but such appearances afford no geological proof of a general cataclysm. It is clear that no devastating wave has passed over the forest zone of Etna since any of the lateral cones before mentioned were thrown up; for none of these heaps of loose sand and scoriæ could have resisted for a moment the denuding action of a violent flood.

To some, perhaps, it may appear that hills of such incoherent materials cannot be of very great antiquity, because the mere action of the atmosphere must, in

* Sedgwick, Anniv. Address to the Geol. Soc. p. 35. Feb. 1831.

the course of several thousand years, have obliterated their original forms. But there is no weight in this objection; for the older hills are covered with trees and herbage, which protect them from waste; and in regard to the newer ones, such is the porosity of their component materials, that the rain which falls upon them is instantly absorbed, and, for the same reason that the rivers on Etna have a subterranean course, there are none descending the sides of the minor cones.

No sensible alteration has been observed in the form of these cones since the earliest periods of which there are memorials; and there seems no reason for anticipating that in the course of the next ten thousand or twenty thousand years they will undergo any great alteration in their appearance, unless they should be shattered by earthquakes or covered by volcanic ejections.

In other parts of Europe, as in Auvergne and Velay, in France, similar loose cones of scoriæ, probably of higher antiquity than the whole mass of Etna, stand uninjured at inferior elevations above the level of the sea.

CHAPTER XIV.

Volcanic eruption in Iceland in 1783 — New island thrown up — Lava currents of Skaptár Jokul, in same year — Their immense volume — Eruption of Jorullo in Mexico — Humboldt's theory of the convexity of the plain of Malpais — Eruption of Galongoon in Java — Submarine volcanos — Graham island, formed in 1831 — Volcanic archipelagos — The Canaries — Teneriffe — Cones thrown up in Lancerote, 1730–36 — Santorin and its contiguous isles — Barren island, in the Bay of Bengal — Mineral composition of volcanic products.

Volcanic eruptions in Iceland. — With the exception of Etna and Vesuvius, the most complete chronological records of a series of eruptions are those of Iceland; for their history reaches as far back as the ninth century of our era; and, from the beginning of the twelfth century, there is clear evidence that, during the whole period, there has never been an interval of more than forty, and very rarely one of twenty years, without either an eruption or a great earthquake. So intense is the energy of the volcanic action in this region, that some eruptions of Hecla have lasted six years without ceasing. Earthquakes have often shaken the whole island at once, causing great changes in the interior, such as the sinking down of hills, the rending of mountains, the desertion by rivers of their channels, and the appearance of new lakes.* New islands have often been thrown up near the coast, some of which

* Von Hoff. vol. ii. p. 393.

still exist; while others have disappeared, either by subsidences or the action of the waves.

In the interval between eruptions, innumerable hot springs afford vent to subterranean heat, and solfataras discharge copious streams of inflammable matter. The volcanos in different parts of this island are observed, like those of the Phlegræan Fields, to be in activity by turns, one vent often serving for a time as a safety-valve to the rest. Many cones are often thrown up in one eruption, and in this case they take a linear direction, running generally from north-east to south-west, from the north-eastern part of the island, where the volcano Krabla lies, to the promontory Reykianas.

New island thrown up in 1783.— The convulsions of the year 1783 appear to have been more tremendous than any recorded in the modern annals of Iceland; and the original Danish narrative of the catastrophe, drawn up in great detail, has since been substantiated by several English travellers, particularly in regard to the prodigious extent of country laid waste, and the volume of lava produced.* About a month previous to the eruption on the mainland, a submarine volcano burst forth in the sea in lat. 63° 25′ N., long. 23° 44′ W., at a distance of thirty miles in a south-west direction

* The first narrative of the eruption was drawn up by Stephensen, then Chief Justice in Iceland, appointed commissioner by the King of Denmark, for estimating the damage done to the country, that relief might be afforded to the sufferers. Henderson was enabled to correct some of the measurements given by Stephensen, of the depth, width, and length of the lava-currents, by reference to the MS. of Mr. Paulson, who visited the tract in 1794, and examined the lava with attention. (Journal of a Residence in Iceland, &c. p. 229.) Some of the principal facts are also corroborated by Dr. Hooker, in his "Tour in Iceland," vol. ii. p. 128.

from Cape Reykianas, and ejected so much pumice, that the ocean was covered with that substance to the distance of 150 miles, and ships were considerably impeded in their course. A new island was thrown up, consisting of high cliffs, within which fire, smoke, and pumice were emitted from two or three different points. This island was claimed by his Danish Majesty, who denominated it Nyöe, or the New Island; but before a year had elapsed, the sea resumed its ancient domain, and nothing was left but a reef of rocks from five to thirty fathoms under water.

Great eruption of Skaptár Jokul.—Earthquakes, which had long been felt in Iceland, became violent on the 11th of June, 1783, when Skaptár Jokul, distant nearly two hundred miles from Nyöe, threw out a torrent of lava, which flowed down into the river Skaptâ, and completely dried it up. The channel of the river was between high rocks, in many places from four hundred to six hundred feet in depth, and near two hundred in breadth. Not only did the lava fill up this great defile to the brink, but it overflowed the adjacent fields to a considerable extent. The burning flood, on issuing from the confined rocky gorge, was then arrested for some time by a deep lake, which formerly existed in the course of the river, between Skaptardal and Aa, which it entirely filled. The current then advanced again, and reaching some ancient lava full of subterraneous caverns, penetrated and melted down part of it; and in some places, where the steam could not gain vent, it blew up a rock, throwing fragments to the height of more than 150 feet. On the 18th of June, another ejection of liquid lava rushed from the volcano, which flowed down with amazing velocity over the surface of the first stream. By the damming up

of the mouths of some of the tributaries of the Skaptâ, many villages were completely overflowed with water, and thus great destruction of property was caused. The lava, after flowing for several days, was precipitated down a tremendous cataract called Stapafoss, where it filled a profound abyss, which that great waterfall had been hollowing out for ages, and, after this, the fiery current again continued its course.

On the 3d of August, fresh floods of lava still pouring from the volcano, a new branch was sent off in a different direction; for the channel of the Skaptâ was now so entirely choked up, and every opening to the west and north so obstructed, that the melted matter was forced to take a new course, so that it ran in a south-east direction, and discharged itself into the bed of the river Hverfisfliot, where a scene of destruction scarcely inferior to the former was occasioned. These Icelandic lavas (like the ancient streams which are met with in Auvergne, and other provinces of Central France), are stated by Stephensen to have accumulated to a prodigious depth in narrow rocky gorges; but when they came to wide alluvial plains, they spread themselves out into broad burning lakes, sometimes from twelve to fifteen miles wide, and one hundred feet deep. When the "fiery lake" which filled up the lower portion of the valley of the Skaptâ had been augmented by new supplies, the lava flowed up the course of the river to the foot of the hills from whence the Skaptâ takes its rise. This affords a parallel case to one which can be shown to have happened at a remote era in the volcanic region of the Vivarais in France, where lava issued from the cone of Thueyts, and while one branch ran down, another more powerful stream flowed up the channel of the river Ardêche.

The sides of the valley of the Skaptâ present superb ranges of basaltic columns of older lavas, resembling those which are laid open in the valleys descending from Mont Dor in Auvergne, where more modern lava-currents, on a scale very inferior in magnitude to those of Iceland, have also usurped the beds of the existing rivers. The eruption of Skaptâr Jokul did not entirely cease till the end of two years; and when Mr. Paulson visited the tract eleven years afterwards, in 1794, he found columns of smoke still rising from parts of the lava, and several rents filled with hot water.*

Although the population of Iceland was very much scattered, and did not exceed fifty thousand, no less than twenty villages were destroyed, besides those inundated by water; and more than nine thousand human beings perished, together with an immense number of cattle, partly by the depredations of the lava, partly by the noxious vapours which impregnated the air, and, in part, by the famine caused by showers of ashes throughout the island, and the desertion of the coasts by the fish.

Immense volume of the lava. — But the extraordinary volume of melted matter produced in this eruption deserves the particular attention of the geologist. Of the two branches, which flowed in nearly opposite directions, the greatest was fifty, and the lesser forty, miles in length. The extreme breadth which the Skaptâ branch attained in the low countries was from twelve to fifteen miles, that of the other about seven. The ordinary height of both currents was one hundred feet, but in narrow defiles it sometimes amounted to

* Henderson's Journal, &c. p. 228.

six hundred. A more correct idea will be formed of the dimensions of the two streams, if we consider how striking a feature they would now form in the geology of England, had they been poured out on the bottom of the sea after the deposition, and before the elevation of our secondary and tertiary rocks. The same causes which have excavated valleys through parts of our marine strata, once continuous, might have acted with equal force on the igneous rocks, leaving, at the same time, a sufficient portion undestroyed to enable us to discover their former extent. Let us, then, imagine the termination of the Skaptâ branch of lava to rest on the escarpment of the inferior and middle oolite, where it commands the vale of Gloucester. The great platform might be one hundred feet thick, and from ten to fifteen miles broad, exceeding any which can be found in Central France. We may also suppose great tabular masses to occur at intervals, capping the summit of the Cotswold Hills between Gloucester and Oxford, by Northleach, Burford, and other towns. The wide valley of the Oxford clay would then occasion an interruption for many miles; but the same rocks might recur on the summit of Cumnor and Shotover Hills, and all the other oolitic eminences of that district. On the chalk of Berkshire, extensive plateaus, six or seven miles wide, would again be formed; and, lastly, crowning the highest sands of Highgate and Hampstead, we might behold some remnants of the current five or six hundred feet in thickness, causing those hills to rival, or even to surpass, in height, Salisbury Craigs and Arthur's Seat.

The distance between the extreme points here indicated would not exceed ninety miles in a direct line; and we might then add, at the distance of nearly two

hundred miles from London, along the coast of Dorsetshire and Devonshire, for example, a great mass of igneous rocks, to represent those of contemporary origin, which were produced beneath the level of the sea, where the island of Nyöe rose up.

Volume of ancient and modern flows of lava compared.— Yet, gigantic as must appear the scale of these modern volcanic operations, we must be content to regard them as perfectly insignificant in comparison to currents of the primeval ages, if we embrace the theoretical views of some geologists of great celebrity. Thus, we are informed by Professor Brongniart, in his last work, that " aux époques géognostiques anciennes, tous les phénomènes géologiques se passoient dans des dimensions *centuples* de celles qu'ils présentent aujourd'hui."* Had Skaptár Jokul, therefore, been a volcano of the olden time, it would have poured forth lavas at a single eruption a hundred times more voluminous than those which were witnessed by the present generation in 1783. But this can never have been intended by M. Brongniart; for were we to multiply the two currents before described by a hundred, and first assume that their height and breadth remain the same, they would stretch out to the length of nine thousand miles, or about half as far again as from the pole to the equator. If, on the other hand, we suppose their length and breadth to remain the same, and multiply their height in an equal proportion, the mean elevation of the volcanic mass becomes ten thousand feet, and its greatest more than double that of the Himalaya mountains. It will immediately be granted

* Tableau des Terrains qui composent l'Ecorce du Globe, p. 52. Paris, 1829.

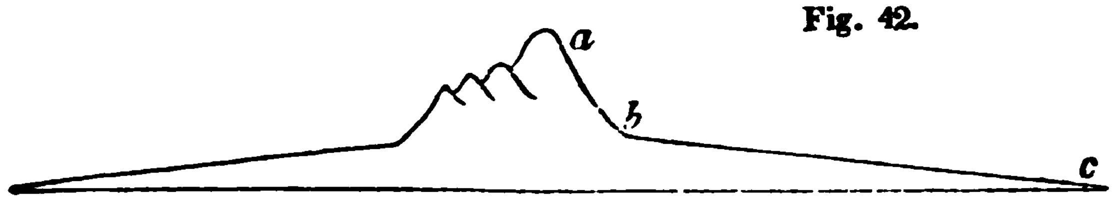
that, among the older formations, no igneous rock of such colossal magnitude has yet been met with; nay, it would be most difficult to point out a mass of ancient date, distinctly referable to a single eruption, which should even rival in volume the matter poured out from Skaptár Jokul in 1783.

Eruption of Jorullo in 1759.—As another example of the stupendous scale of modern volcanic eruptions, I may mention that of Jorullo in Mexico, in 1759. The great region to which this mountain belongs has already been described. The plain of Malpais forms part of an elevated platform, between two and three thousand feet above the level of the sea, and is bounded by hills composed of basalt, trachyte, and volcanic tuff, clearly indicating that the country had previously, though probably at a remote period, been the theatre of igneous action. From the era of the discovery of the New World to the middle of the last century, the district had remained undisturbed, and the space, now the site of the volcano, which is thirty-six leagues distant from the nearest sea, was occupied by fertile fields of sugar-cane and indigo, and watered by the two brooks Cuitimba and San Pedro. In the month of June, 1759, hollow sounds of an alarming nature were heard, and earthquakes succeeded each other for two months, until, at the end of September, flames issued from the ground, and fragments of burning rocks were thrown to prodigious heights. Six volcanic cones, composed of scoriæ and fragmentary lava, were formed on the line of a chasm which ran in the direction from N.N.E. to S.S.W. The least of these cones was 300 feet in height; and Jorullo, the central volcano, was elevated 1600 feet above the level of the plain. It sent forth great streams of basaltic lava,

containing included fragments of granitic rocks, and its ejections did not cease till the month of February, 1760.*

Humboldt visited the country more than forty years after this occurrence, and was informed by the Indians, that when they returned, long after the castastrophe, to the plain, they found the ground uninhabitable from the excessive heat. When he himself visited the place, there appeared, around the base of the cones, and spreading from them, as from a centre, over an extent of four square miles, a mass of matter of a convex form, about 550 feet high at its junction with the cones, and gradually sloping from them in all directions towards the plain. This mass was still in a

Fig. 42.



a, Summit of Jorullo. b, c, Inclined plane sloping at angle of 6° from the base of the cones.

heated state, the temperature in the fissures being on the decrease from year to year, but in 1780 it was still sufficient to light a cigar at the depth of a few inches. On this slightly convex protuberance, the slope of which must form an angle of about 6° with the horizon, were thousands of flattish conical mounds, from six to nine feet high, which, as well as large fissures traversing the plain, acted as fumeroles, giving out clouds of sulphuric acid and hot aqueous vapour. The two small rivers before mentioned disappeared during the eruption, losing themselves below the eastern extremity of the plain, and re-appearing as hot springs at its western limit.

* Daubeny on Volcanos, p. 337.

Cause of the convexity of the plain of Malpais.— Humboldt attributed the convexity of the plain to inflation from below; supposing the ground, for four square miles in extent, to have risen up in the shape of a bladder to the elevation of 550 feet above the plain in the highest part. But Mr. Scrope has suggested that the phenomena may be accounted for far more naturally, by supposing that lava flowing simultaneously from the different orifices, and principally from Jorullo, united into a sort of pool or lake. As they were poured forth on a surface previously flat, they would, if their liquidity was not very great, remain thickest and deepest near their source, and diminish in bulk from thence towards the limits of the space which they covered. Fresh supplies were probably emitted successively during the course of an eruption which lasted more than half a year; and some of these, resting on those first emitted, might only spread to a small distance from the foot of the cone, where they would necessarily accumulate to a great height.

The showers, also, of loose and pulverulent matter from the six craters, and principally from Jorullo, would be composed of heavier and more bulky particles near the cones, and would raise the ground at their base, where, mixing with rain, they might have given rise to the stratum of black clay which is described as covering the lava. The small conical mounds (called "hornitos," or little ovens) may resemble those five or six small hillocks which existed in 1823 on the Vesuvian lava, and sent forth columns of vapour, having been produced by the disengagement of elastic fluids heaving up small dome-shaped masses of lava. The fissures mentioned by Humboldt

as of frequent occurrence, are such as might naturally accompany the consolidation of a thick bed of lava, contracting as it congeals; and the disappearance of rivers is the usual result of the occupation of the lower part of a valley or plain by lava, of which there are many beautiful examples in the old lava-currents of Auvergne. The heat of the "hornitos" is stated to have diminished from the first; and Mr. Bullock, who visited the spot many years after Humboldt, found the temperature of the hot spring very low,— a fact which seems clearly to indicate the gradual congelation of a subjacent bed of lava, which from its immense thickness may have been enabled to retain its heat for half a century. The reader may be reminded, that when we thus suppose the lava near the volcano to have been, together with the ejected ashes, more than five hundred feet in depth, we merely assign a thickness which the current of Skaptâr Jokul attained in some places in 1783.

Hollow sound of the plain when struck.— Another argument adduced in support of the theory of inflation from below, was, the hollow sound made by the steps of a horse upon the plain; which, however, proves nothing more than that the materials of which the convex mass is composed are light and porous. The sound called "rimbombo" by the Italians is very commonly returned by *made ground* when struck sharply; and has been observed not only on the sides of Vesuvius and other volcanic cones where there is a cavity below, but in plains such as the Campagna di Roma, composed in a great measure of tuff and porous volcanic rocks. The reverberation, however, may perhaps be assisted by grottos and caverns, for these may be as numerous in the lavas of Jorullo as in many

of those of Etna; but their existence would lend no countenance to the hypothesis of a great arched cavity, four square miles in extent, and in the centre 550 feet high.*

No recent eruptions of Jorullo.— In a former edition I stated that I had been informed by Captain Vetch, that in 1819 a tower at Guadalaxara was thrown down by an earthquake, and that ashes, supposed to have come from Jorullo, fell at the same time at Guanaxuato, a town situated 140 English miles from the volcano. But Mr. Burkart, a German director of mines, who examined Jorullo in 1827, ascertained that there had been no eruption there since Humboldt's visit in 1803. He went to the bottom of the crater, and observed a slight evolution of sulphurous acid vapours, but the "hornitos" had entirely ceased to send forth steam. During the twenty-four years intervening between his visit and that of Humboldt, vegetation had made great progress on the flanks of the new hills, the rich soil of the surrounding country was once more covered with luxuriant crops of sugarcane and indigo, and there was an abundant growth of natural underwood on all the uncultivated tracts.†

Galongoon, Java, 1822.— The mountain of Galongoon (or Gulung Gung) was in 1822 covered by a dense forest, and situated in a fruitful and thickly-peopled part of Java. There was a circular hollow at its summit, but no tradition existed of any former eruption. In July, 1822, the waters of the river Kunir, one of those which flowed from its flanks, became for a time hot and turbid. On the 8th of October following a loud explosion was heard, the earth shook, and

* See Scrope on Volcanos, p. 267.

† Leonhard and Bronn's Neues Jahrbuch, 1835, p. 36.

immense columns of hot water and boiling mud, mixed with burning brimstone, ashes, and lapilli of the size of nuts, were projected from the mountain like a water-spout, with such prodigious violence that large quantities fell beyond the river Tandoi, which is forty miles distant. Every valley within the range of this eruption became filled with a burning torrent, and the rivers, swoln with hot water and mud, overflowed their banks, and carried away great numbers of the people, who were endeavouring to escape, and the bodies of cattle, wild beasts, and birds. A space of twenty-four miles between the mountain and the river Tandoi was covered to such a depth with bluish mud that people were buried in their houses, and not a trace of the numerous villages and plantations throughout that extent was visible. Within this space the bodies of those who perished were buried in mud and concealed, but near the limits of the volcanic action they were exposed, and strewed over the ground in great numbers, partly boiled and partly burnt.

It was remarked, that the boiling mud and cinders were projected with such violence from the mountain, that while many remote villages were utterly destroyed and buried, others much nearer the volcano were scarcely injured.

The first eruption lasted nearly five hours, and on the following days the rain fell in torrents, and the rivers, densely charged with mud, deluged the country far and wide. At the end of four days (October 12th) a second eruption occurred more violent than the first, in which hot water and mud were again vomited, and great blocks of basalt were thrown to the distance of seven miles from the volcano. There was at the same time a violent earthquake, and in one account it is

stated that the face of the mountain was utterly changed, its summits broken down, and one side, which had been covered with trees, became an enormous gulf in the form of a semicircle. This cavity was about midway between the summit and the plain, and surrounded by steep rocks, said to be newly heaped up during the eruption. New hills and valleys are said to have been formed, and the rivers Banjarang and Wulan changed their course, and in one night (October 12th) 2000 persons were killed.

The first intimation which the inhabitants of Bandong received of this calamity on the 8th of October was the news that the river Wulan was bearing down into the sea the dead bodies of men, and the carcasses of stags, rhinoceroses, tigers, and other animals. The Dutch painter Payen determined to travel from thence to the volcano, and he found that the quantity of the ashes diminished as he approached the base of the mountain. He alludes to the altered form of the mountain after the 12th, but does not describe the new semicircular gulf on its side.

The official accounts state that 114 villages were destroyed, and above 4000 persons killed.*

Submarine volcanos. — Although we have every reason to believe that volcanic eruptions as well as earthquakes are common in the bed of the sea, it was not to be expected that many opportunities would occur to scientific observers of witnessing the phenomena. The crews of vessels have sometimes reported that they have seen in different places sulphureous smoke, flame, jets of water, and steam, rising

* Van der Boon Mesch, de Incendiis Montium Javæ, &c. Lugd. Bat. 1826; and Official Report of the President, Baron Van der Capellen; also, Von Buch, Iles Canar. p. 424.

up from the sea, or they have observed the waters greatly discoloured, and in a state of violent agitation, as if boiling. New shoals have also been encountered, or a reef of rocks just emerging above the surface, where previously there was always supposed to have been deep water. On some few occasions the gradual formation of an island by a submarine eruption has been observed, as that of Sabrina, in the year 1811, off St. Michael's, in the Azores. The throwing up of ashes in that case, and the formation of a cone about three hundred feet in height, with a crater in the centre, closely resembled the phenomena usually accompanying a volcanic eruption on land. Sabrina was soon washed away by the waves. Previous eruptions in the same part of the sea were recorded to have happened in 1691 and 1720. The rise of Nyōe, also, a small island off the coast of Iceland, in 1783, has already been alluded to; and another volcanic isle was produced by an eruption near Reikiavig, on the same coast, in June, 1830.*

Graham Island,† 1831. — We have still more recent and minute information respecting the appearance, in 1831, of a new volcanic island in the Mediterranean, between the S. W. coast of Sicily and that projecting part of the African coast where ancient Carthage

* Journ. de Géol. tome i.

† In a former edition, I selected the name of Sciacca out of seven which had been proposed; but the Royal and Geographical Societies have now adopted Graham Island; a name given by Captain Senhouse, R. N., the first who succeeded in landing on it. The seven rival names are Nerita, Ferdinanda, Hotham, Graham, Corrao, Sciacca, Julia. As the isle was visible for only about three months, this is an instance of a wanton multiplication of synonyms which has scarcely ever been outdone even in the annals of zoology and botany.

stood. The site of the island was not any part of the great shoal, or bank, called "Nerita," as was first asserted, but a spot where Captain W. H. Smyth had found, in his survey a few years before, a depth of more than one hundred fathoms' water.*

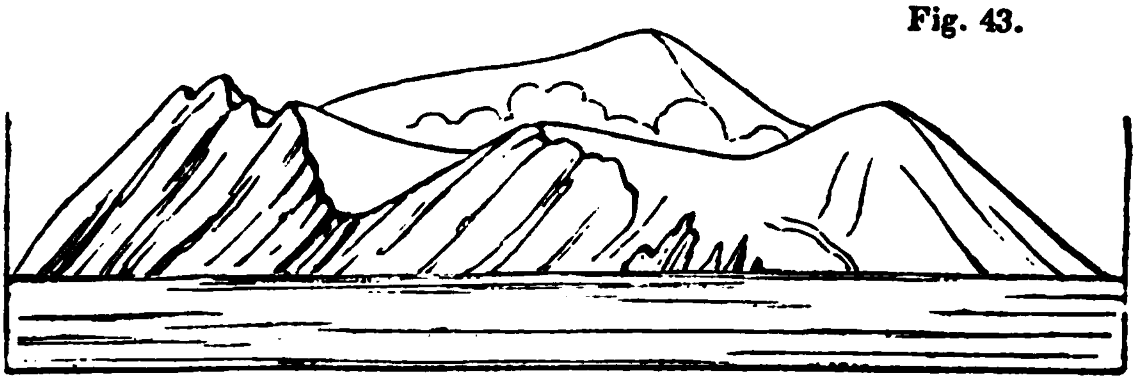
The position of the island (lat. 37° 8′ 30″ N., long. 12° 42′ 15″ E.) was about thirty miles S. W. of Sciacca, in Sicily, and thirty-three miles N. E. of Pantellaria.† On the 28th of June, about a fortnight before the eruption was visible, Sir Pulteney Malcolm, in passing over the spot in his ship, felt the shocks of an earthquake, as if he had struck on a sand-bank; and the same shocks were felt on the west coast of Sicily, in a direction from S.W. to N. E. About the 10th of July, John Corrao, the captain of a Sicilian vessel, reported that, as he passed near the place, he saw a column of water like a water-spout, sixty feet high, and eight hundred yards in circumference, rising from the sea, and soon afterwards a dense steam in its place, which ascended to the height of 1800 feet. The same Corrao, on his return from Gergenti, on the 18th of July, found a small island, twelve feet high, with a crater in its centre, ejecting volcanic matter, and immense columns of vapour; the sea around being covered with floating cinders and dead fish. The scoriæ were of a chocolate colour, and the water which boiled in the circular basin was of a dingy red. The eruption continued with great violence to the end of the same month; at which time the island was visited by several persons, and, among others, by Captain Swinburne, R. N., and M. Hoffmann, the Prussian geologist. It was then from fifty to ninety

* Phil. Trans. 1832, p. 255.

† Journ. of Roy. Geograph. Soc. 1830–31.

feet in height, and three quarters of a mile in circumference. By the 4th of August it became, according

Fig. 43.



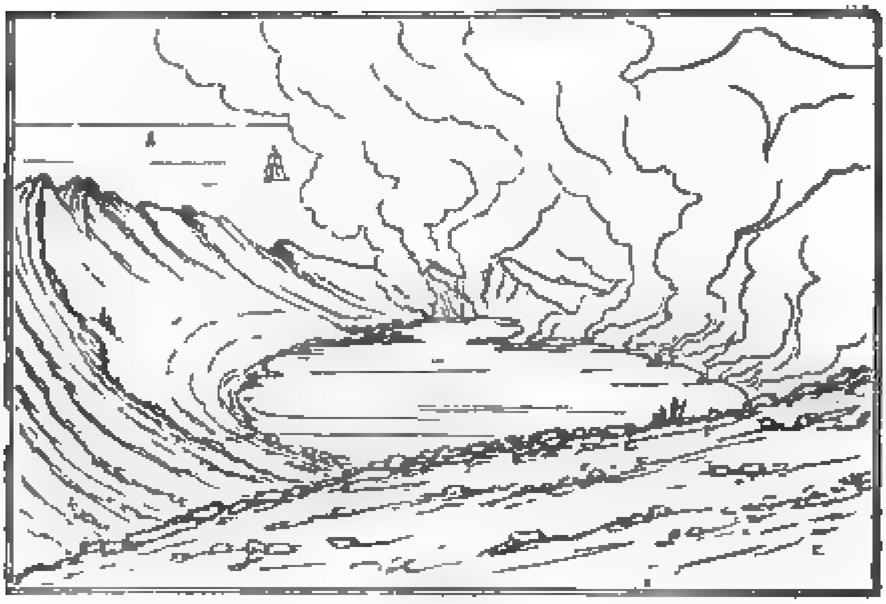
Form of the cliffs of Graham Island, as seen from S. S. E., distant one mile, 7th August, 1831.*

to some accounts, above 200 feet high, and three miles in circumference; after which it began to diminish in size by the action of the waves, and was only two miles round on the 25th of August; and on the 3d of September, when it was carefully examined by Captain Wodehouse, only three-fifths of a mile in circumference; its greatest height being then 107 feet. At this time the crater was about 780 feet in circumference. On the 29th of September, when it was visited by Mons. C. Prevost, its circumference was reduced to about seven hundred yards. It was composed entirely of incoherent ejected matter, scoriæ, pumice, and lapilli, forming regular strata, some of which are described as having been parallel to the steep inward slope of the crater, while the rest were inclined outwards, like those of Vesuvius.† When the arrangement of the ejected materials has been determined by their falling continually on two steep slopes, that of the external cone and that of the crater,

* Phil. Trans. part ii., 1832, reduced from drawings by Captain Wodehouse, R. N.

† See memoir by M. C. Prevost, Ann. des Sci. Nat. tom. xxiv.

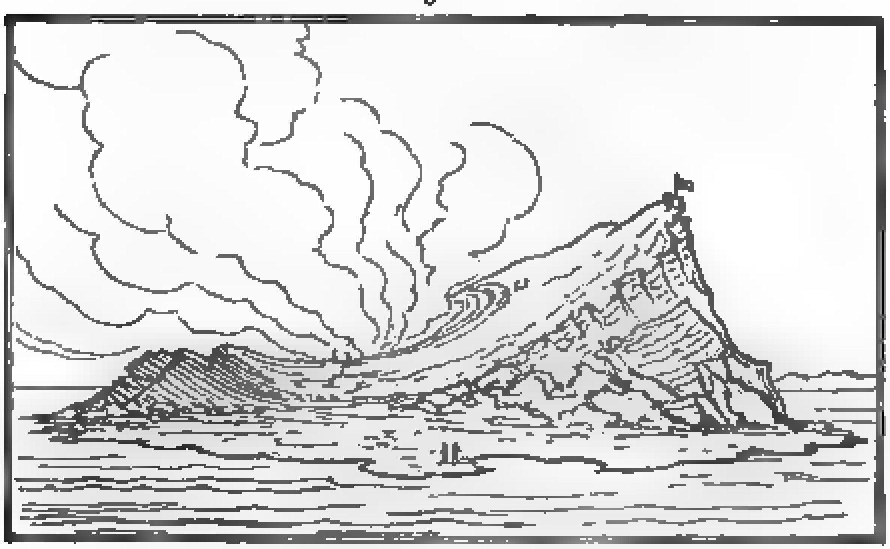
Fig. 44.



View of the interior of Graham Island, 29th Sept. 1831.

which is always a hollow inverted cone, a transverse section would probably resemble that given in the an-

Fig. 45.

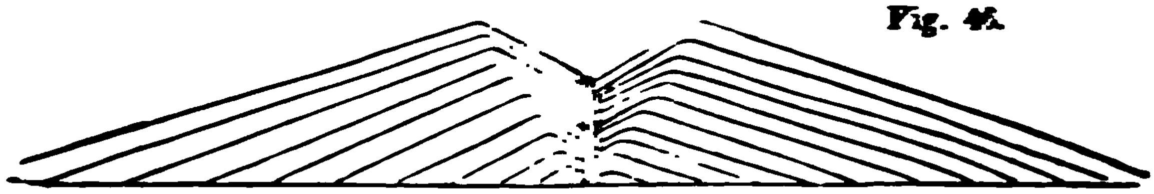


Graham Island, 29th Sept. 1831.*

* In the annexed sketch, (Fig. 45.), drawn by M. Joinville, who accompanied M. C. Prevost, the beds seem to slope towards the centre of the crater; but I am informed by Mr. Prevost that these lines were not intended by the artist to represent the dip of the beds.

nexed figure (46.). But when I visited Vesuvius, in 1828, I saw no beds of scoriæ inclined towards the

Fig. 46.



axis of the cone (see Fig. 31. p. 182.). Such may have once existed; but the explosions or subsidences, or whatever causes produced the great crater of 1822, had possibly destroyed them.

Few of the pieces of stone thrown out from Graham Island exceeded a foot in diameter. Some fragments of dolomitic limestone were intermixed; but these were the only non-volcanic substances. During the month of August, there occurred on the S. W. side of the new island a violent ebullition and agitation of the sea, accompanied by the constant ascension of a column of dense white steam, indicating the existence of a second vent at no great depth from the surface. Towards the close of October, no vestige of the crater remained, and the island was nearly levelled with the surface of the ocean, with the exception, at one point, of a small monticule of sand and scoriæ. It was reported that, at the commencement of the year following (1832), there was a depth of 150 feet where the island had been: but this account was quite erroneous; for in the early part of that year Captain Swinburne found a shoal and discoloured water there, and towards the end of 1833 a dangerous reef existed, of an oval figure, about three-fifths of a mile in extent. In the centre was a black rock, of the diameter of about twenty-six fathoms, from nine to eleven feet under water; and round this rock are banks of black volcanic stones and loose sand. At the distance of

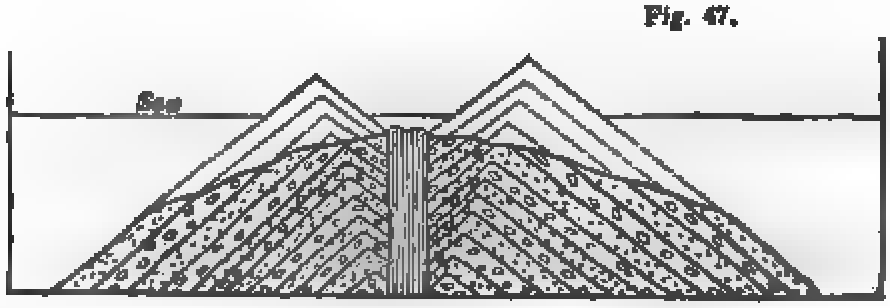
sixty fathoms from this central mass, the depth increased rapidly. There was also a second shoal at the distance of 450 feet S. W. of the great reef, with fifteen feet of water over it, also composed of rock, surrounded by deep sea. We can scarcely doubt that the rock in the middle of the larger reef is solid lava, which rose up in the principal crater, and that the second shoal marks the site of the submarine eruption observed in August, 1831, to the S. W. of the island.

From the whole of the facts above detailed, it appears that a hill eight hundred feet or more in height was formed by a submarine volcanic vent, of which the upper part (only about two hundred feet high) emerged above the waters, so as to form an island. This cone must have been equal in size to one of the largest of the lateral volcanos on the flanks of Etna, and about half the height of the mountain Jorullo in Mexico, which was formed in the course of nine months, in 1759. In the centre of the new volcano a large cavity was kept open by gaseous discharges, which threw out scoriæ; and fluid lava probably rose up in this cavity. It is not uncommon for small subsidiary craters to open near the summit of a cone, and one of these may have been formed in the case of Graham island; a vent, perhaps, connected with the main channel of discharge which gave passage in that direction to elastic fluids, scoriæ, and melted lava. It does not appear that, either from this duct, or from the principal vent, there was any overflowing of lava; but melted rock may have flowed from the flanks or base of the cone (a common occurrence on land), and may have spread in a broad sheet over the bottom of the sea.

The dotted lines in the annexed figure are an imagi-

nary restoration of the upper part of the cone, now removed by the waves: the strong lines represent the part of the volcano which is still under water; in the centre is a great column, or dike, of solid lava, two hundred feet in diameter, supposed to fill the space by

Fig. 47.



Supposed section of Graham Island. (C Maclaren.*)

which the gaseous fluids rose; and on each side of the dike is a stratified mass of scoriæ and fragmentary lava. The solid nucleus of the reef, where the black rock is now found, withstands the movements of the sea; while the surrounding loose tuffs are cut away to a somewhat lower level. In this manner the lava, which was the lowest part of the island, or to speak more correctly, which scarcely ever rose above the level of the sea when the island existed, has now become the highest point in the reef.

No appearances observed, either during the eruption or since the island disappeared, give the least support to the opinion promulgated by some writers, that part of the ancient bed of the sea had been lifted up bodily.

The solid products, says Dr. John Davy, whether they consisted of sand, light cinders, or vesicular lava, differed more in form than in composition. The lava contained augite; and the specific gravity was 2·07 and 2·70. When the light spongy cinder, which floated

* Geol. of Fife and the Lothians, p. 41. Edin. 1839.

on the sea, was reduced to fine powder by trituration, and the greater part of the entangled air got rid of, it was found to be of the specific gravity 2.64; and that of some of the sand which fell in the eruption was 2.75*; so that the materials equalled ordinary granites in weight and solidity. The only gas evolved in any considerable quantity was carbonic acid.†

Canary Islands — Teneriffe.— The Peak of Teneriffe, which is about 12,000 feet high, stands, says Von Buch, like a tower encircled by its fosse and bastion. The bastion consists, like the semicircular escarpment of Somma turned towards Vesuvius, of precipitous cliffs, composed of trachyte, basalt, coarse conglomerates, and tuffs, traversed by volcanic dikes, mostly vertical, and of basalt. These cliffs vary in height from 1000 to 1800 feet, and are supposed by Von Buch to have been heaved up into their present position by a force exerted from below, in accordance with the theory proposed by the same author for the origin of the cones of Vesuvius and Etna.

The highest crater of the peak has merely disengaged sulphurous vapours ever since it has been known to Europeans; but an eruption happened in June, 1798, not far from the summit, and others are recorded, which poured out streams of lava from great heights, besides many which have broken out nearer the level of the sea. All these, however, seem to be dependent on one great centre of eruption, or on that open channel communicating between the interior of the earth and the atmosphere, which terminates in the highest crater of the peak.

We may consider Teneriffe, then, as having been from a remote period the principal and habitual vent

* Phil. Trans. 1832, p. 243. † Ibid. p. 249.

of the volcanic archipelago of the Canaries. The discharges which have taken place in the contiguous isles of Palma, Lancerote, and the rest, may be of a subsidiary kind, and have probably been most frequent and violent when the great crater had been partially sealed up, just as the violent eruptions of Ischia or that of Monte Nuovo coincided with the dormant state of Vesuvius.

Eruption in Lancerote, 1730 *to* 1736.—The effects of one of these insular eruptions in the Canaries, which happened in Lancerote, between the years 1730 and 1736, were very remarkable; and a detailed description has been published by Von Buch, who had an opportunity, when he visited that island in 1815, of comparing the accounts transmitted to us of that event, with the present state and geological appearances of the country.* On the first of September, 1730, the earth split open on a sudden two leagues from Yaira. In one night a considerable hill of ejected matter was thrown up; and a few days later, another vent opened, and gave out a lava-stream, which overran Chinanfaya and other villages. It flowed first rapidly, like water, but became afterwards heavy and slow, like honey. On the 7th of September an immense rock was protruded from the bottom of the lava, with a noise like thunder, and the stream was forced to change its course from N. to N.W., so that St. Catalina and other villages were overflowed.

Whether this mass was protruded by an earthquake,

* This account was principally derived by Von Buch from the MS. of Don Andrea Lorenzo Curbeto, curate of Yaira, the point where the eruption began.—Ueber einen vulcanischen Ausbruch auf der Insel Lanzerote.

or was a mass of ancient lava, blown up like that before mentioned in 1783 in Iceland, is not explained.

On the 11th of September more lava flowed out, and covered the village of Maso entirely, and, for the space of eight days, precipitated itself with a horrible roar into the sea. Dead fish floated on the waters in indescribable multitudes, or were thrown dying on the shore. After a brief interval of repose, three new openings broke forth immediately from the site of the consumed St. Catalina, and sent out an enormous quantity of lapilli, sand, and ashes. On the 28th of October the cattle throughout the whole country dropped lifeless to the ground, suffocated by putrid vapours, which condensed and fell down in drops. On the 1st of December a lava stream reached the sea, and formed an island, round which dead fish were strewed.

Number of cones thrown up. — It is unnecessary here to give the details of the overwhelming of other places by fiery torrents, or of a storm which was equally new and terrifying to the inhabitants, as they had never known one in their country before. On the 10th of January, 1731, a high hill was thrown up, which, on the same day, precipitated itself back again into its own crater; fiery brooks of lava flowed from it to the sea. On the 3d of February a new cone arose. Others weie thrown up in March, and poured forth lava streams. Numerous other volcanic cones were subsequently formed in succession, till at last their number amounted to about thirty. In June, 1731, during a renewal of the eruptions, all the banks and shores in the western part of the island were covered with dying fish, of different species, some of which had never before been seen. Smoke and flame arose

from the sea, with loud detonations. These dreadful commotions lasted without interruption for *five successive years*, so that a great emigration of the inhabitants became necessary.

Their linear direction.—As to the height of the new cones, Von Buch was assured that the formerly great and flourishing St. Catalina lay buried under hills 400 feet in height; and he observes that the most elevated cone of the series rose 600 feet above its base, and 1378 feet above the sea, and that several others were nearly as high. The new vents were all arranged *in one line*, about two geographical miles long, and in a direction nearly east and west. If we admit the probability of Von Buch's conjecture, that these vents opened along the line of a cleft, it seems necessary to suppose that this subterranean fissure was only prolonged upwards to the surface by degrees, and that the rent was narrow at first, as is usually the case with fissures caused by earthquakes. Lava and elastic fluids might escape from some point on the rent where there was least resistance, till, the first aperture becoming obstructed by ejections and the consolidation of lava, other orifices burst open in succession along the line of the original fissure. Von Buch found that each crater was lowest on that side on which lava had issued; but some craters were not breached, and were without any lava-streams. In one of these were open fissures, out of which hot vapours rose, which in 1815 raised the thermometer to 145° Fahrenheit, and was probably at the boiling point lower down. The exhalations seemed to consist of aqueous vapour; yet they could not be pure steam, for the crevices were encrusted on either side by siliceous sinter (an opal-like hydrate of silica of a white colour), which ex-

tended almost to the middle. This important fact attests the length of time during which chemical processes continue after eruptions, and how open fissures may be filled up laterally by mineral matter, sublimed from volcanic exhalations. The lavas of this eruption covered nearly a third of the whole island, often forming on slightly inclined planes great horizontal sheets several square leagues in area, resembling very much the basaltic platforms of Auvergne.

Pretended distinction between ancient and modern lavas. — One of the new lavas was observed to contain masses of olivine of an olive-green colour, resembling those which occur in one of the lavas of the Vivarais. Von Buch supposes the great crystals of olivine to have been derived from a previously existing basalt melted up by the new volcanos; but we have scarcely sufficient data to bear out such a conjecture. The older rocks of the island consist, in a great measure, of that kind of basaltic lava called dolerite, sometimes columnar, and partly of common basalt and amygdaloid. Some recent lavas assumed, on entering the sea, a prismatic form, and so much resembled the older lavas of the Canaries, that the only geological distinction which Von Buch appears to have been able to draw between them was, that they did not alternate with conglomerates, like the ancient basalts. Some modern writers have endeavoured to discover, in the abundance of these conglomerates, a proof of the dissimilarity of the volcanic action in ancient and modern times; but this character is more probably attributable to the difference between submarine operations and those on the land. All the blocks and imperfectly rounded fragments of lava, transported, during the intervals of eruption, by rivers and torrents, into the adjoining

sea, or torn by the continued action of the waves from cliffs which are undermined, must accumulate in stratified breccias and conglomerates, and be covered again and again by other lavas. This is now taking place on the shores of Sicily, between Catania and Trezza, where the sea breaks down and covers the shore with blocks and pebbles of the modern lavas of Etna; and on parts of the coast of Ischia, where numerous currents of trachyte are in like manner undermined in lofty precipices. So often, then, as an island is raised in a volcanic archipelago by earthquakes from the deep, the fundamental and (relatively to all above) the oldest lavas will often be distinguishable from those formed by subsequent eruptions on dry land, by their alternation with beds of sandstone and fragmentary rocks.

The supposed want of identity, then, between the volcanic phenomena of different epochs resolves itself into the marked difference between the operations simultaneously in progress, above and below the waters. Such, indeed, is the source, as was before stated in the First Book (Chap. V.), of many of our strongest theoretical prejudices in geology. No sooner do we study and endeavour to explain submarine appearances, than we feel, to use a common expression, out of our element; and, unwilling to concede that our extreme ignorance of processes now continually going on can be the cause of our perplexity, we take refuge in a "pre-existent order of nature."

Recent formation of oolitic travertin in Lancerote. — Throughout a considerable part of Lancerote, the old lavas are covered by a thin stratum of limestone, from an inch to two feet in thickness. It is of a hard stalactitic nature, sometimes oolitic, like the Jura lime-

stone, and contains fragments of lava and terrestrial shells, chiefly helices and spiral bulimi. It sometimes rises to the height of 800 feet above the level of the sea. Von Buch imagines, that this remarkable superstratum has been produced by the furious north-west storms, which in winter drive the spray of the sea in clouds over the whole island; from whence calcareous particles may be deposited stalactitically. Mr. Darwin informs me that he found a limestone in St. Helena, the harder parts of which correspond precisely to the stone of Lancerote. He attributes the origin of this rock in St. Helena not to the spray of the sea, but to drifting by violent winds of the finer particles of shells from the sea-beach. Some parts of this drift are subsequently dissolved by atmospheric moisture, and re-deposited, so as to convert calcareous sand into oolite.

Recent eruption in Lancerote. — From the year 1736 to 1815, when Von Buch visited Lancerote, there had been no eruption; but, in August, 1824, a crater opened near the port of Rescif, and formed, by its ejections, in the space of twenty-four hours, a considerable hill. Violent earthquakes preceded and accompanied this eruption.*

Santorin. — The outer portion of Santorin, in the Grecian archipelago, is composed of three islands, Santorin, Therasia, and Aspronisi, which surround an almost circular gulf of about two leagues in diameter from south to north, and a league and a half from east to west. The island of Santorin itself forms more than two thirds of the circuit, and is composed entirely of volcanic matter, with the exception of its southern

* Férussac, Bulletin des Sci. Nat. tome v. p. 45. 1825. The volcano was still burning when the account here cited was written.

part, which rises to three times the height of the igneous rocks in the island, and is formed of granular limestone and argillaceous schist.* This mountainous part is the original and fundamental nucleus of the isle; and, according to M. Bory de St. Vincent, its strata have the same direction as those of the other isles of the Grecian archipelago, from N.N.W. to S.S.E. Their inclination and fractures have no rela-

Fig. 48.

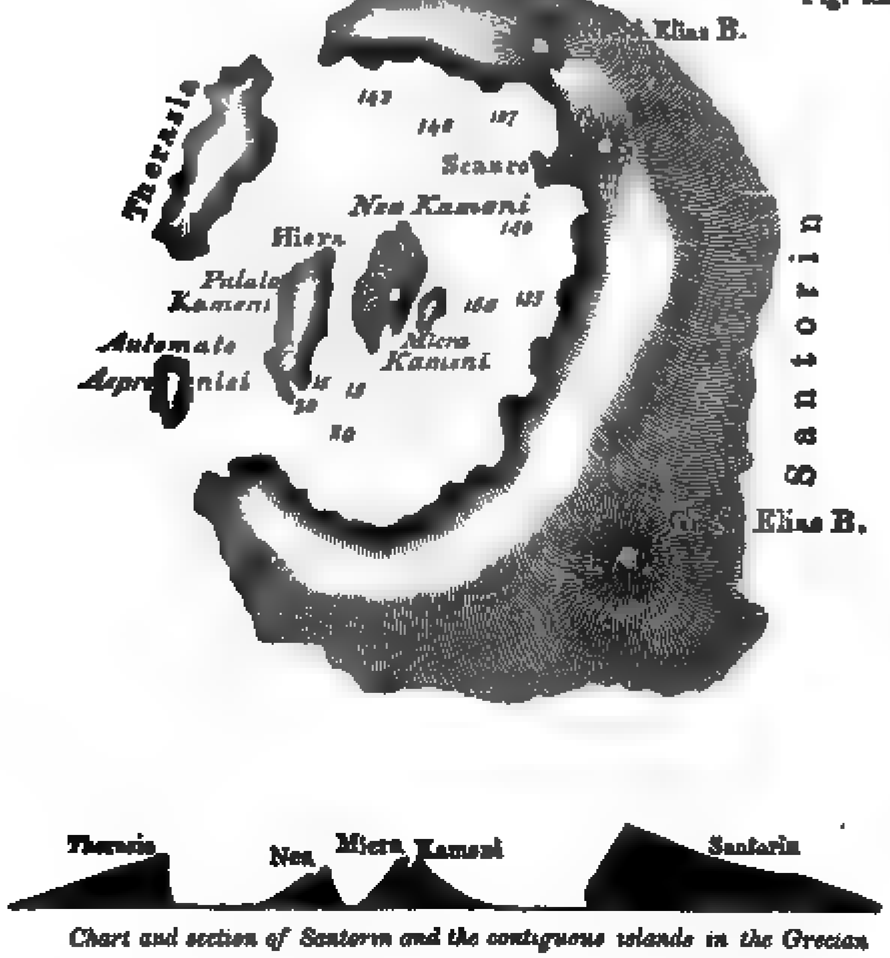


Chart and section of Santorin and the contiguous islands in the Grecian Archipelago. (Von Buch.)

tion to the position of the newer volcanic rocks, of which the remainder of the group of islands is exclu-

* Virlet, Bull. de la Soc. Géol. de France, tom. iii. p. 103.

sively composed. The volcanic mass, which must be considered as quite an independent formation, consists of alternating beds of trachytic lava, tuff, and conglomerate, which dip on every side from the centre of the gulf to the circumference. Towards the gulf they present uniformly a high and steep escarpment, the precipices in Santorin rising to the height of more than eight hundred feet, and plunging at once into a sea from eight hundred to a thousand feet deep. Each of the islands is capped by an enormous mass of white tufaceous conglomerate, from forty to fifty feet in thickness; which is not pumice, as has often been stated. The beds of lava and tuff, above mentioned, are accumulated in great numbers one upon another, and of unequal thickness: although disposed with great regularity, when viewed as a whole, they are found to be discontinuous, as in Vesuvius, when any particular mass is traced to some distance.

Before discussing the merits of the theory proposed to account for the structure of this volcanic group, it will be desirable to give a brief sketch of its history, so far as it is known. Pliny relates that the separation of Therasia from Thera, or Santorin, took place after a violent earthquake, in the year 236 before the Christian era. From his work, and other authorities, we also learn that the year 186 B. C. gave birth, in the middle of the gulf, to Hiera, or the Sacred Isle, still called Hiera-Nisos, or sometimes Palaia Kameni (Old Burnt Island.) There seems to have been no eruption then, but simply an upheaving of solid lava. In the year 19 of our era, Thia (the Divine) made its appearance above the surface of the waters. This small island has no longer a separate existence, having been joined to Hiera, from which it was only 250 paces distant:

Hiera itself increased in size in 726, and in 1427. In 1573, the small island of Micra-Kameni appeared, a small cone and crater, one hundred feet high, raised by successive ejections.

On the 27th of September, 1650, there was an eruption three or four miles north of Santorin, altogether outside of the gulf, immediately after violent earthquakes. It gave rise to no new islet, but greatly elevated the bottom of the sea on the spot. The eruption lasted three months; many houses on Santorin were destroyed; and the vapours of sulphur and hydrogen killed more than fifty persons, and more than one thousand domesticated animals. A wave fifty feet high broke upon the rocks of the Isle of Nio, about four leagues distant, and advanced 350 yards into the interior of the island of Sikino, which is seven leagues off. The sea also broke upon Santorin, overthrew two churches, and exposed to view a village on each side of the mountain of St. Stephen, both of which must have been overwhelmed by showers of volcanic matter during some former eruption.*

Lastly, in 1707 and 1709, Nea-Kameni was produced between Palaia and Micra (old and lesser) Kamenis. This isle was composed originally of two distinct parts, the first which rose was called the White Island — a mass of pumice, extremely porous. Goree the Jesuit, who was then in Santorin, says that the rock " cut like bread," and that, when the inhabitants landed on it, they found a multitude of full-grown fresh oysters adhering to it, which they eat.† This island was afterwards covered, in great part, by the matter ejected from the crater of the second island,

* Virlet, Bull. de la Soc. Géol. de France, tom. iii. p. 103.

† Phil. Trans. No. 332.

produced at the same time, called "Black Island," being composed partly of brown trachyte. This volcano, now named Nea (or New) Kameni, continued in eruption, at intervals, during 1711 and 1712, and formed a cone 330 feet above the level of the sea: there are now, therefore, two channels of direct communication between the atmosphere and volcanic foci beneath the group of Santorin; namely, the craters of New and Little Kameni.

A curious fact is mentioned by M. Virlet, respecting the supposed slow and progressive rise of a solid ridge at the bottom of the sea. Twenty years ago there was a depth of fifteen fathoms water between the lesser Kameni and the port of Phira, in Santorin. In 1830, when MM. Virlet and Bory visited the spot, there was only a depth of between three and four fathoms; and they found that the bottom consisted of a hard rock, probably trachyte, measuring about eight hundred yards from E. to W., and five hundred only from N. to S. Beyond this the sea deepens rapidly on all sides. From these facts, and from information obtained on the spot, M. Virlet infers that the bed of the sea is rising gradually, and that, in all probability, a new island may one day appear, without commotion, above the surface. He suggests that the solid crust of rock now slowly rising may resemble a cork carried up by the fermentation of the liquor on which it floats.*

After the descriptions above given, we shall naturally be led to compare the three exterior islands which encircle the Gulf of Santorin to the semicircular escarpment of Somma, while the smaller islets thrown up since the historical era, in the centre of the gulf, may

* See M. Virlet's Memoir, before cited.

be likened to the modern cone, or rather cones, of Vesuvius.

Von Buch supposes that a solid dome of trachyte is now rising in the centre of the bay, and that the expansive force from below will, one day, burst an opening, and cause the uplifted rocks to dip on all sides from within outwards.* Undoubtedly the porous mass of white pumice upheaved in 1707 (see p. 282.) implies the partial elevation of solid matter, and may be compared perhaps to the solid crust of scoriæ, which is often capable of supporting heavy weights on the surface of lava-currents still in motion. But such data are far too scanty and obscure to enable us to speculate with profit on the connection of the causes which may now be uplifting the bed of the sea in the place above mentioned, and those processes by which the more ancient volcanic rocks of Santorin acquired their present configuration.

It is naturally objected by M. Virlet, that if a mass like Santorin, which, including its submarine foundations, must be from 1700 to 2000 feet in thickness, was suddenly and violently heaved up from a horizontal position, we might expect to find the rocks traversed every where by rents which would diverge from the principal centre of movement to the circumference of the circular area. But these rents are wanting, as are all signs of the shattering and dislocation of the mass. At the same time he adduces a fact which seems conclusive against the notion, that the three exterior islands owe their peculiar structure to the upheaval of horizontal beds into a conical form. In examining the various currents of lava (the existence of which was unknown to Van Buch, who had

* Poggendorf's Annalen, 1836, p. 183.

not visited Santorin), it was found that the vesicles, or pores which abound in them, are lengthened in the several directions in which they would naturally be drawn out, if the melted matter had flowed towards different points of the compass from the summit of a conical mountain, of which the present islands were the base. The force of this argument will be appreciated by those who are aware that bubbles of confined gas in a fluid in motion assume an oval form, and that the direction of the longer axis coincides always with that of the stream. It is also observed by M. Virlet, that the deep stratum of white tufaceous conglomerate by which all the islands are uniformly covered, may well be supposed to have resulted from heavy showers of ejected matter which fell during that paroxysmal explosion, by which the great cone was originally blown up, truncated, and emptied in its interior.

The manner in which the external walls were separated into three distinct islands is easily conceived. The principal breaches are to the N. W., the quarter most exposed to the waves and currents. On this side, the earthquake of 236 B. C., mentioned by Pliny, may have caused a fissure, which allowed the waves and currents to penetrate and sweep away the incoherent tuffs and conglomerates, just as they washed away Graham Island; and if there happened to be little or no lava at certain points, the waves would in such places readily force a passage.*

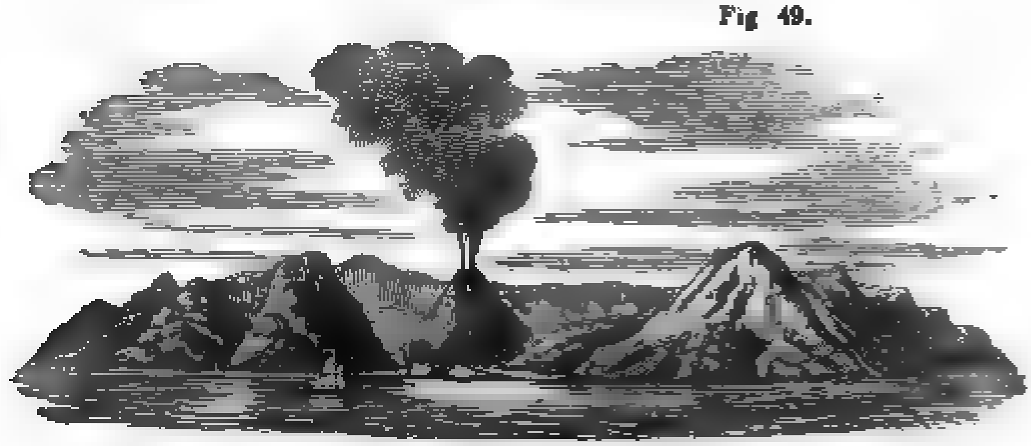
The dimensions of the gulf of Santorin are not greater than we may suppose to result from the truncation and falling in of large volcanic cones. We shall afterwards see that Papandayang, formerly one of the

* Virlet, ibid.

loftiest volcanos in Java, lost, in 1772, about four thousand feet of its former height.* During an eruption in 1444, accompanied by a tremendous earthquake, the summit of Etna was destroyed, and an enormous crater was left, from which lava flowed. The segment of that crater may still be seen near the Casa Inglese, and, when complete, it must have measured several miles in diameter. If Etna had again been truncated down to the upper margin of the woody region, a circular basin would thus have been formed, thirty Italian miles in circumference, exceeding by five or six miles the circuit of the Gulf of Santorin. Yet we have every reason to believe that the beds of felspathic and basaltic lavas, with the alternating tuffs and breccias, would, in that part of the great cone of Etna, dip on all sides off from the centre, at angles of from about 15° to 30°, to every point of the compass.

Barren Island.— There is great analogy between the structure of Barren Island in the Bay of Bengal,

Fig 49.



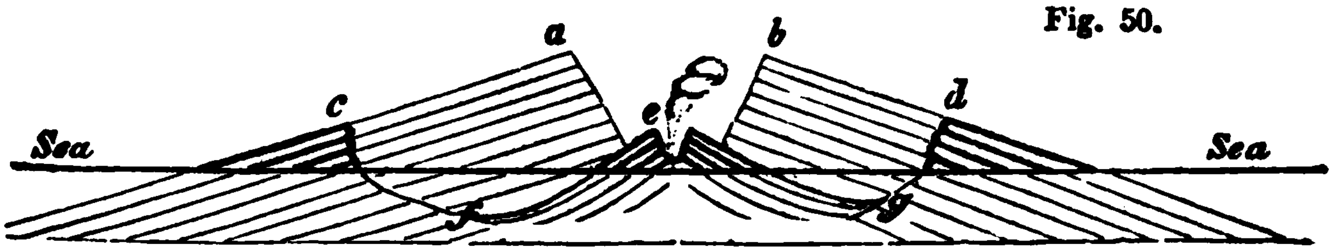
Cone and Crater of Barren Island, in the Bay of Bengal.— Height of the central cone 1848 feet. (Von Buch.)

lat. 12°, 15'., and that of Santorin last described. When seen from the ocean, this island presents, on almost

* See chap. xvii.

all sides, a surface of bare rocks, rising, with a moderate acclivity, towards the interior; but at one point there is a cleft, by which we can penetrate into the centre, and there discover that it is occupied by a great circular basin, filled by the waters of the sea, and bordered all around by steep rocks, in the midst of which rises a volcanic cone, very frequently in eruption. The summit of this cone is 1848 feet in height, corresponding to that of the circular border which incloses the basin; so that it can be seen from the sea only through the ravine. It is most probable that the exterior inclosure of Barren Island, *c*, *d* (Fig. 50.), is nothing more than the remains of a truncated cone, *c*, *a*, *b*, *d*, a great portion of which has been removed by engulphments, or by explosions which preceded the formation of the new interior cone *f*, *e*, *g*.

Fig. 50.



Supposed section of Barren Island, in the Bay of Bengal.

Mineral composition of volcanic products. — The mineral called felspar forms in general more than half of the mass of modern lavas. When it is in great excess, lavas are called trachytic; they consist generally of a base of compact felspar, in which crystals of glassy felspar are disseminated.* When augite (or pyroxene) predominates, lavas are termed basaltic. But others of an intermediate composition occur, which from their colour have been called gray-stones. The

* See Glossary.

abundance of quartz, forming distinct crystals or concretions, characterizes the granitic and other ancient rocks, now generally considered by geologists as of igneous origin: whereas that mineral is rarely exhibited in a separate form in recent lavas, although silica enters largely into their composition. Hornblende, so common in hypogene rocks, or those commonly called "primary," is rare in modern lava; nor does it enter largely into rocks of any age in which augite abounds. It should, however, be stated, that the experiments of M. Gustavus Rose have made it very questionable, whether the minerals called hornblende and augite can be separated as distinct species, as their different varieties seem to pass into each other, whether we consider the characters derived from their angles of crystallization, their chemical composition, or their specific gravity. The difference in form of the two substances may be explained by the different circumstances under which they have been produced; the form of hornblende being the result of slower cooling. Crystals of augite have been met with in the scoriæ of furnaces, but never those of hornblende; and crystals of augite have been obtained by melting hornblende in a platina crucible, but hornblende itself has not been formed artificially.* Mica occurs plentifully in some recent trachytes, but is rarely present where augite is in excess.

Frequency of eruptions, and nature of subterranean igneous rocks. — When we speak of the igneous rocks of our own times, we mean that small portion which, in violent eruptions, is forced up by elastic fluids to the surface of the earth, — the sand, scoriæ, and lava, which cool in the open air. But we cannot obtain ac-

* Bulletin de la Soc. Géol. de France, tom. ii. p. 206.

cess to that which is congealed far beneath the surface under great pressure, equal to that of many hundred, or many thousand atmospheres.

During the last century, about fifty eruptions are recorded of the five European volcanic districts, of Vesuvius, Etna, Volcano, Santorin, and Iceland; but many beneath the sea in the Grecian archipelago and near Iceland may doubtless have passed unnoticed. If some of them produced no lava, others, on the contrary, like that of Skaptâr Jokul, in 1783, poured out melted matter for five or six years consecutively; which cases, being reckoned as single eruptions, will compensate for those of inferior strength. Now, if we consider the active volcanos of Europe to constitute about a fortieth part of those already known on the globe, and calculate that, one with another, they are about equal in activity to the burning mountains in other districts, we may then compute that there happen on the earth about 2000 eruptions in the course of a century, or about twenty every year.

However inconsiderable, therefore, may be the superficial rocks which the operations of fire produce on the surface, we must suppose the subterranean changes now constantly in progress to be on the grandest scale. The loftiest volcanic cones must be as insignificant, when contrasted to the products of fire in the nether regions, as are the deposits formed in shallow estuaries when compared to submarine formations accumulating in the abysses of the ocean. In regard to the characters of these volcanic rocks, formed in our own times in the bowels of the earth, whether in rents and caverns, or by the cooling of lakes of melted lava, we may safely infer that the rocks are heavier and less porous than ordinary lavas, and more crystalline,

although composed of the same mineral ingredients. As the hardest crystals produced artificially in the laboratory require the longest time for their formation, so we must suppose that where the cooling down of melted matter takes place by insensible degrees, in the course of ages, a variety of minerals will be produced far harder than any formed by natural processes within the short period of human observation.

These subterranean volcanic rocks, moreover, cannot be stratified in the same manner as sedimentary deposits from water, although it is evident that when great masses consolidate from a state of fusion, they may separate into natural divisions; for this is seen to be the case in many lava-currents. We may also expect that the rocks in question will often be rent by earthquakes, since these are common in volcanic regions; and the fissures will often be injected with similar matter, so that dikes of crystalline rock will traverse masses of similar composition. It is also clear, that no organic remains can be included in such masses, as also that these deep-seated igneous formations considered in mass must underlie all the strata containing organic remains, because the heat proceeds from below upwards, and the intensity required to reduce the mineral ingredients to a fluid state must destroy all organic bodies in rocks included in the midst of them.

If by a continued series of elevatory movements, such masses shall hereafter be brought up to the surface, in the same manner as sedimentary marine strata have, in the course of ages, been upheaved to the summit of the loftiest mountains, it is not difficult to foresee what perplexing problems may be presented to the geologist. He may then, perhaps, study in some

mountain chain the very rocks produced at the depth of several miles beneath the Andes, Iceland, or Java, in the time of Leibnitz, and draw from them the same conclusion which that philosopher derived from certain igneous products of high antiquity; for he conceived our globe to have been, for an indefinite period, in the state of a comet, without an ocean, and uninhabitable alike by aquatic or terrestrial animals.

CHAPTER XV.

EARTHQUAKES AND THEIR EFFECTS.

Earthquakes and their effects — Deficiency of ancient accounts — Ordinary atmospheric phenomena — Changes produced by earthquakes in modern times considered in chronological order — Earthquake in Syria, 1837 — Earthquakes in Chili in 1837 and 1835 — Isle of Santa Maria raised ten feet — Chili, 1822 — Extent of country elevated — Aleppo and Ionian Isles — Earthquake of Cutch in 1819 — Subsidence in the Delta of the Indus — Island of Sumbawa in 1815 — Town of Tomboro submerged — Earthquake of Caraccas in 1812 — New Madrid in 1811 — Changes in the valley of the Mississippi — Aleutian Islands in 1806 — Reflections on the earthquakes of the nineteenth century — Earthquakes in Quito, Quebec, &c. — Java, 1786 — sinking down of large tracts — Japan Isles, 1783.

In the sketch before given of the geographical boundaries of volcanic regions, I stated, that although the points of eruption are but thinly scattered, constituting mere spots on the surface of those vast districts, yet the subterranean movements extend simultaneously over immense areas. We may now proceed to consider the changes which these movements produce on the surface, and in the internal structure of the earth's crust.

Deficiency of ancient accounts.— It is only within the last century and a half since Hooke first promulgated his views respecting the connection between geological phenomena and earthquakes, that the per-

manent changes effected by these convulsions have excited attention. Before that time, the narrative of the historian was almost exclusively confined to the number of human beings who perished, the number of cities laid in ruins, the value of property destroyed, or certain atmospheric appearances which dazzled or terrified the observers. The creation of a new lake, the engulphing of a city, or the raising of a new island, are sometimes, it is true, adverted to, as being too obvious, or of too much geographical or political interest, to be passed over in silence. But no researches were made expressly with a view of ascertaining the amount of depression or elevation of the ground, or any particular alterations in the relative position of sea and land; and very little distinction was made between the raising of soil by volcanic ejections, and the upheaving of it by forces acting from below. The same remark applies to a very large proportion of modern accounts; and how much reason we have to regret this deficiency of information appears from this, that in every instance where a spirit of scientific inquiry has animated the eye-witnesses of these events, facts calculated to throw light on former modifications of the earth's structure are recorded.

Phenomena attending earthquakes.— As I shall confine myself almost entirely, in the following notice of earthquakes, to the changes brought about by them in the configuration of the earth's crust, I may mention, generally, some accompaniments of these terrible events which are almost uniformly commemorated in history, that it may be unnecessary to advert to them again. Irregularities in the seasons preceding or following the shocks; sudden gusts of wind, interrupted by dead calms; violent rains at unusual seasons, or in

countries where such phenomena are almost unknown; a reddening of the sun's disk, and a haziness in the air, often continued for months; an evolution of electric matter, or of inflammable gas from the soil, with sulphurous and mephitic vapours; noises under-ground, like the running of carriages, or the discharge of artillery, or distant thunder; animals uttering cries of distress, and evincing extraordinary alarm, being more sensitive than men of the slightest movement; a sensation like sea-sickness, and a dizziness in the head, experienced by men: — these, and other phenomena, which are still more remotely connected with our present subject as geologists, have recurred again and again at distant ages, and in all parts of the globe.

I shall now begin the enumeration of earthquakes with the latest authentic narratives, and so carry back the survey retrospectively, that I may bring before the reader, in the first place, the minute and circumstantial details of modern times, and thus enable him, by observing the extraordinary amount of change within the last 150 years, to perceive how great must be the deficiency in the meagre annals of earlier eras.

EARTHQUAKES OF THE NINETEENTH CENTURY.*

Syria, January, 1837.—It has been remarked that earthquakes affect elongated areas. The violent shock

* Since the publication of the first edition of this work, numerous accounts of recent earthquakes have been published; but as they do not illustrate any new principle, I cannot insert them all, as they would enlarge too much the size of my work. Among the most violent may be mentioned those of March, 1829, near Alicant in Murcia—that of Sept. 1827, at Lehore, East Indies

which devastated Syria in 1837 was felt on a line 500 miles in length by ninety in breadth;* more than 6000 persons perished, deep rents were caused in solid rocks, and new hot springs burst out at Tabereah.

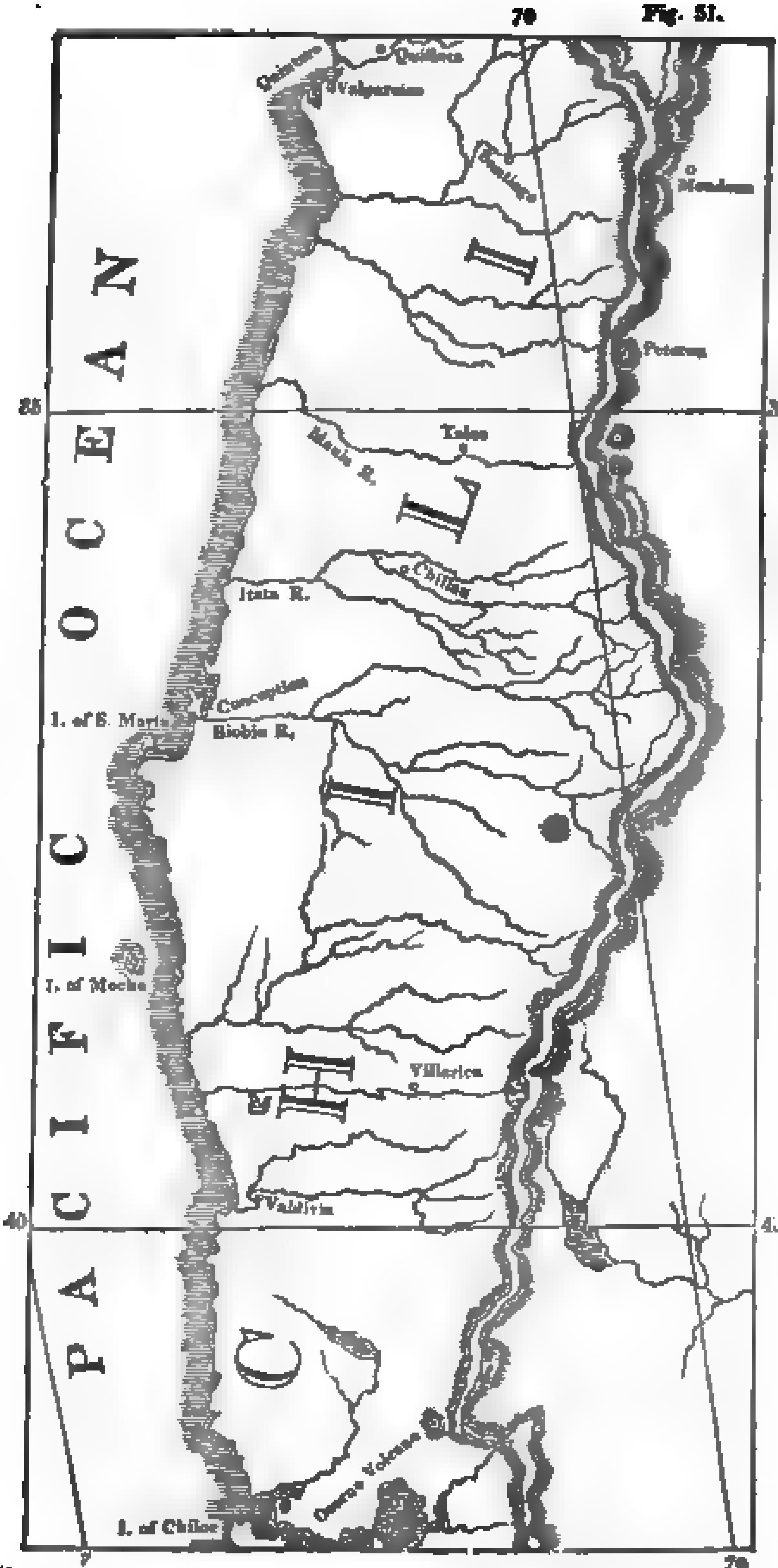
Chili — Valdivia, 1837.— One of the latest earthquakes by which the position of solid land is known to have been permanently altered is that which occurred in Chili, on November 7. 1837. On that day Valdivia was destroyed by an earthquake, and a whaler, commanded by Captain Coste, was violently shaken at sea, and lost her masts, in lat. 43° 38′ S. in sight of the land. The captain went on the 11th of December following to a spot near the island of Lemus, one of the Chonos archipelago, where he had anchored two years before, and found that the bottom of the sea had been raised more than eight feet. Some rocks formerly covered at all times by the sea were now constantly exposed, and an enormous quantity of shells and fish in a decaying state, which had been thrown there by the waves, or suddenly laid dry during the earthquake, attested the recent date of the occurrence. The whole coast was strewed with uprooted trees.†

— of Jan. 15. 1832, which almost destroyed Foligno, in Italy — June 24. 1830, in China, in Tayming, North of Houan — March 9. 1830, in the Caucasus at Kislier — April 1833, Manilla — 1833, Isle of Lissa in Adriatic, and Opus. The late Von Hoff published, from time to time, in Poggendorf's Annalen, lists of eathquakes which happened between 1821 and 1836; and, by consulting these, the reader will perceive that every month is signalized by one or many convulsions in some part of the globe.

* Darwin, Geol. Proceedings, vol. ii. p. 658.

† Dumoulin, Comptes Rendus de l'Acad. des Sci., Oct. 1838, p. 706.

Fig. 51.



70
35
40
PACIFIC OCEAN
CHILI
Valparaiso
Mendoza
Talca
Maule R.
Chillan
Itata R.
Concepcion
I. of S. Maria
Biobio R.
I. of Mocha
Villarica
Valdivia
I. of Chiloe

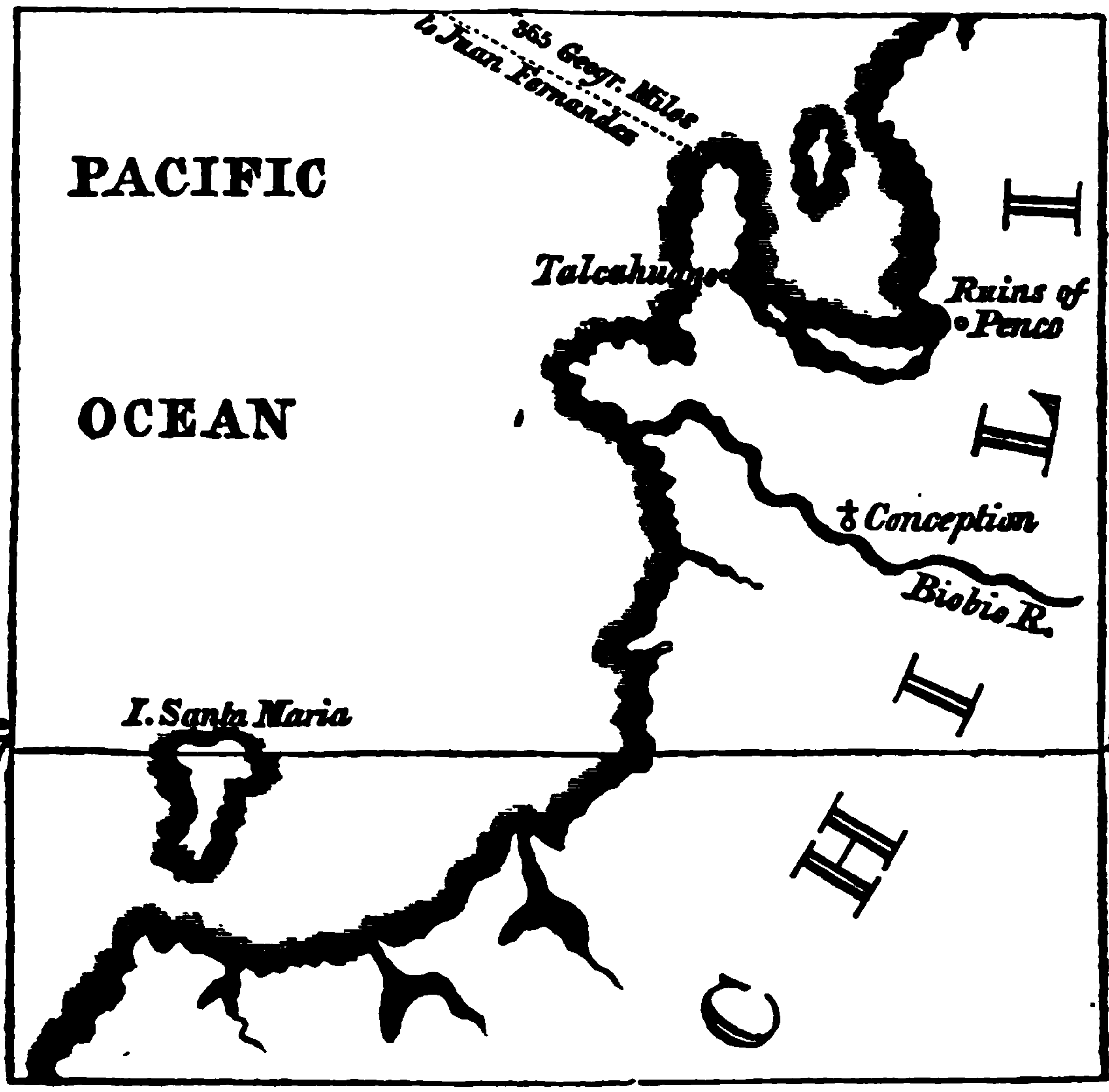
Chili — *Conception*, 1835. — Fortunately we have a still more detailed account of the geographical changes produced in the same country on the 20th of February, 1835. An earthquake was then felt at all places between Copiapo and Chiloe, from north to south, and from Mendoza to Juan Fernandez, from east to west. "Vessels," says Mr. Caldcleugh, "navigating the Pacific, within 100 miles of the coast, experienced the shock with considerable force."* Conception, Talcahuano, Chilian, and other towns were thrown down. From the account of Captain Fitz Roy, R. N., who was then employed in surveying the coast, we learn that after the shock the sea retired in the Bay of Conception, and the vessels grounded, even those which had been lying in seven fathoms water; all the shoals were visible, and soon afterwards a wave rushed in and then retreated, and was followed by two other waves. The vertical height of these waves does not appear to have been much greater than from sixteen to twenty feet, although they rose to much greater heights when they broke upon a sloping beach.

According to Mr. Caldcleugh and Mr. Darwin, the whole volcanic chain of the Chilian Andes, a range 150 miles in length, was in a state of unusual activity, both during the shocks and for some time preceding and after the convulsion, and lava was seen to flow from the crater of Osorno. (See Map, fig. 51.) The island of Juan Fernandez, distant 365 geographical miles from Chili, was violently shaken at the same time, and devastated by a great wave. A submarine volcano broke out there near Bacalao Head, about a mile from the shore, in sixty-nine fathoms water, and illumined the whole island during the night.†

* Phil. Trans. 1836, p. 21. † Ibid. p. 25.

"At Conception," says Captain Fitz Roy, "the earth opened and closed rapidly in numerous places. The direction of the cracks was not uniform, though generally from south-east to north-west. The earth was not quiet for three days after the great shock, and more than 300 shocks were counted between the 20th February and the 4th of March. The loose earth of the valley of the Biobio was everywhere parted from the solid rocks which bound the plain, there being an opening between them from an inch to a foot in width.

Fig. 52.



"For some days after the 20th of February, the sea at Talcahuano," says Captain Fitz Roy, "did not rise to

the usual marks by four or five feet vertically. When walking on the shore, even at high water, beds of dead mussles, numerous chitons, and limpets, and withered sea-weed, still adhering, though lifeless, to the rocks on which they had lived, everywhere met the eye." But this difference in the relative level of the land and sea gradually diminished, till in the middle of April the water rose again to within two feet of the former high water mark. It might be supposed that these changes of level merely indicated a temporary disturbance in the set of the currents or in the height of the tides at Talcahuano; but, on considering what occurred in the neighbouring island of Santa Maria, Captain Fitz Roy concluded that the land had been raised four or five feet in February, and that it had returned in April to within two or three feet of its former level.

Santa Maria, the island just alluded to, is about seven miles long and two broad, and about twenty-five miles south-west of Conception. (See Map, fig. 52.) The phenomena observed there are most important. "It appeared," says Captain Fitz Roy, who visited Santa Maria twice, the first time at the end of March, and afterwards in the beginning of April, "that the southern extremity of the island had been raised eight feet, the middle nine, and the northern end upwards of ten feet. On steep rocks, where vertical measures could be correctly taken, beds of dead mussels were found ten feet above high water mark. One foot lower than the highest bed of mussels, a few limpets and chitons were seen adhering to the rock where they had grown. Two feet lower than the same, dead mussels, chitons, and limpets were abundant.

"An extensive rocky flat lies around the northern parts of Santa Maria. Before the earthquake this flat

was covered by the sea, some projecting rocks only showing themselves. Now, the whole flat is exposed, and square acres of it are covered with dead shell-fish, the stench arising from which is abominable. By this elevation of the land the southern port of Santa Maria has been almost destroyed; little shelter remaining there, and very bad landing." The surrounding sea is also stated to have become shallower in exactly the same proportion as the land had risen; the soundings having diminished a fathom and a half everywhere around the island.

At Tubal, also, to the south-east of Santa Maria, the land was raised six feet, at Mocha two feet, but no elevation could be ascertained at Valdivia.

Among other effects of the catastrophe it is stated, that cattle standing on a steep slope, near the shore, were rolled down into the sea, and many others were washed off by the great wave from low land and drowned.*

In November of the same year, (1835), Conception was shaken by a severe earthquake, and on the same day Osorno, at the distance of 400 miles, renewed its activity. These facts prove not only the connection of earthquakes with volcanic eruptions in this region, but also the vast extent of the subterranean areas, over which the disturbing cause acts simultaneously.

Ischia, 1828.—On the 2nd of February the whole island of Ischia was shaken by an earthquake, and in the October following I found all the houses in Casamicciol still without their roofs. On the sides of a ravine between that town and Forio, I saw masses of greenish tuff, which had been thrown down. The hot-

* Darwin's Journ. of Travels in South America, in voyage of H. M. ship Beagle, p. 372.

spring of Rita, which was nearest the centre of the movement, was ascertained by M. Covelli to have increased in temperature, showing, as he observes, that the explosion took place below the reservoirs which heat the thermal waters.*

Bogota, 1827.—On the 16th of November, 1827, the plain of Bogota, in New Granada, or Colombia, was convulsed by an earthquake, and a great number of towns were thrown down. Torrents of rain swelled the Magdalena, sweeping along vast quantities of mud and other substances, which emitted a sulphurous vapour and destroyed the fish. Popayan, which is distant two hundred geographical miles S. S. W. of Bogota, suffered greatly. Wide crevices appeared in the road of Guanacas, leaving no doubt that the whole of the Cordilleras sustained a powerful shock. Other fissures opened near Costa, in the plains of Bogota, into which the river Tunza immediately began to flow.† It is worthy of remark, that in all such cases the ancient gravel bed of a river is deserted, and a new one formed at a lower level; so that a want of relation in the position of alluvial beds to the existing water-courses may be no test of the high antiquity of such deposits, at least in countries habitually convulsed by earthquakes. Extraordinary rains accompanied the shocks before mentioned; and two volcanos are said to have been in eruption in the mountain-chain nearest to Bogota.

Chili, 1822.—On the 19th of November, 1822, the coast of Chili was visited by a most destructive earthquake. The shock was felt simultaneously throughout a space of 1200 miles from north to south. St. Jago,

* Biblioth. Univ. Oct. 1828, p. 157.; and Férussac, Bulletin, &c., tome xi. p. 227.

† Phil. Mag. July, 1828, p. 37.

Valparaiso, and some other places were greatly injured. When the district round Valparaiso was examined on the morning after the shock, it was found that the coast, for a considerable distance, was raised above its former level.* At Valparaiso the elevation was three feet, and at Quintero about four feet. Part of the bed of the sea, says Mrs. Graham, remained bare and dry at high water, "with beds of oysters, mussels, and other shells adhering to the rocks on which they grew, the fish being all dead, and exhaling most offensive effluvia." †

An old wreck of a ship, which before could not be approached, became accessible from the land, although its distance from the original sea-shore had not altered.‡ It was observed, that the water-course of a mill, at the distance of about a mile from the sea, gained a fall of fourteen inches, in little more than one hundred yards; and from this fact it is inferred that the rise in some parts of the inland country was far more considerable than on the borders of the ocean.§ Part of the coast thus elevated consisted of granite, in which parallel fissures were caused, some of which were traced for a mile and a half inland. Cones of earth, about four feet high, were thrown up in several districts, by the forcing up of water mixed with sand through funnel-shaped hollows, — a phenomenon very common in Calabria, and the explanation of which will hereafter be considered. Those houses in Chili of which the foundations were on rock were less damaged than such as were built on alluvial soil.

* See Geol. Trans. vol. i., second series; and also Journ. of Sci., 1824, vol. xvii. p. 40.

† Geol. Trans., vol. i., second series, p. 415. ‡ Ibid.

§ Journ. of Sci. vol. xvii. p. 42.

Mr. Cruckshanks, an English botanist, who resided in the country during the earthquake, has informed me that some rocks of greenstone at Quintero, a few hundred yards from the beach, which had always been under water till the shock of 1822, have since been uncovered when the tide is at half-ebb; and he states that, after the earthquake, it was the general belief of the fishermen and inhabitants of the Chilian coast, *not* that the land had risen, but that the ocean had permanently retreated.

Dr. Meyen, a Prussian traveller, who visited Valparaiso in 1831, says that on examining the rocks both north and south of the town, nine years after the event, he found, in corroboration of Mrs. Graham's account, that remains of animals and sea-weed, the *Lessonia* of Bory de St. Vincent, which has a firm ligneous stem, still adhered to those rocks which in 1822 had been elevated above high water mark.* According to the same author, the whole coast of Central Chili was raised about four feet, and banks of marine shells were laid dry on many parts of the coast. He observed similar banks, elevated at unknown periods, in several places, especially at Copiapo, where the species all agree with those now living in the ocean. Mr. Freyer also, who resided some years in South America, has confirmed these statements †; but Mr. Cuming, a gentleman well known by his numerous discoveries in conchology, and who resided at Valparaiso during and after the earthquake, could detect no proofs of the rise of the land, nor any signs of a change of level. On the contrary, he states, that

* Reise um die erde; and see Dr. Meyen's letter cited Foreign Quart. Rev. No. 33. p. 13. 1836.

† Geol. Soc. Proceedings, No. 40. p. 179., Feb. 1835.

the water at spring tides rose after the earthquake to the same point on a wall near his house, which it had reached before the shocks.* On the other hand, Mr. Darwin obtained evidence that the remains of an ancient wall, formerly washed by the sea, and now 11½ feet above high water mark, acquired several feet of this additional elevation during the earthquake of 1822.†

The shocks continued up to the end of September, 1823; even then, forty-eight hours seldom passed without one, and sometimes two or three were felt during twenty-four hours. Mrs. Graham observed, after the earthquake of 1822, that, besides a beach newly raised above high water mark, there were several older elevated lines of beach one above the other, consisting of shingle mixed with shells, extending in a parallel direction to the shore, to the height of fifty feet above the sea.‡

Extent of country elevated. — By some observers it has been supposed that the whole country from the foot of the Andes to a great distance under the sea was upraised in 1822, the greatest rise being at the distance of about two miles from the shore. "The rise upon the coast was from two to four feet: — at the distance of a mile inland it must have been from five to six, or seven feet.§ It has also been conjectured by the same eye-witnesses to the convulsion, that the area over which this permanent alteration of level extended may have been equal to 100,000 square miles. Although the increased fall of certain

* Cuming, Geol. Proceedings, No. 42. p. 213.

† Proceedings Geol. Soc. vol. ii. p. 447.

‡ Geol. Trans. vol. i., second series, p. 415.

§ Journal of Sci. vol. xvii. pp. 40. 45.

water-courses may have afforded some ground for this conjecture, it must be considered as very hypothetical, and the estimate may have exceeded or greatly fallen short of the truth. It may nevertheless be useful to reflect on the enormous amount of change which this single convulsion occasioned, if the extent of country moved upward really amounted to 100,000 square miles,— an extent just equal to half the area of France, or about five-sixths of the area of Great Britain and Ireland. If we suppose the elevation to have been only three feet on an average, it will be seen that the mass of rock added to the continent of America by the movement, or, in other words, the mass previously below the level of the sea, and after the shocks permanently above it, must have contained fifty-seven cubic miles in bulk; which would be sufficient to form a conical mountain two miles high (or about as high as Etna), with a circumference at the base of nearly thirty-three miles. We may take the mean specific gravity of the rock at 2·655,— a fair average, and a convenient one in such computations, because at such a rate a cubic yard weighs two tons. Then, assuming the great pyramid of Egypt, if solid, to weigh, in accordance with an estimate before given, six million tons, we may state the rock added to the continent by the Chilian earthquake to have more than equalled 100,000 pyramids.

But it must always be borne in mind that the weight of rock here alluded to constituted but an insignificant part of the whole amount which the volcanic forces had to overcome. The whole thickness of rock between the surface of Chili and the subterranean foci of volcanic action may be many miles or leagues deep. Say that the thickness was only two miles, even then

the mass which changed place and rose three feet being 200,000 cubic miles in volume, must have exceeded in weight 363 million pyramids.

It may be instructive to consider these results in connection with others already obtained from a different source, and to compare the working of two antagonist forces — the levelling power of running water, and the expansive energy of subterranean heat. How long, it may be asked, would the Ganges require, according to data before explained, to transport to the sea a quantity of solid matter equal to that which may have been added to the land by the Chilian earthquake? The discharge of mud in one year by the Ganges equalled the weight of sixty pyramids. In that case it would require seventeen centuries and a half before the river could bear down from the continent into the sea a mass equal to that gained by the Chilian earthquake. In about half that number of centuries, perhaps, the united waters of the Ganges and Burrampooter might accomplish the operation.

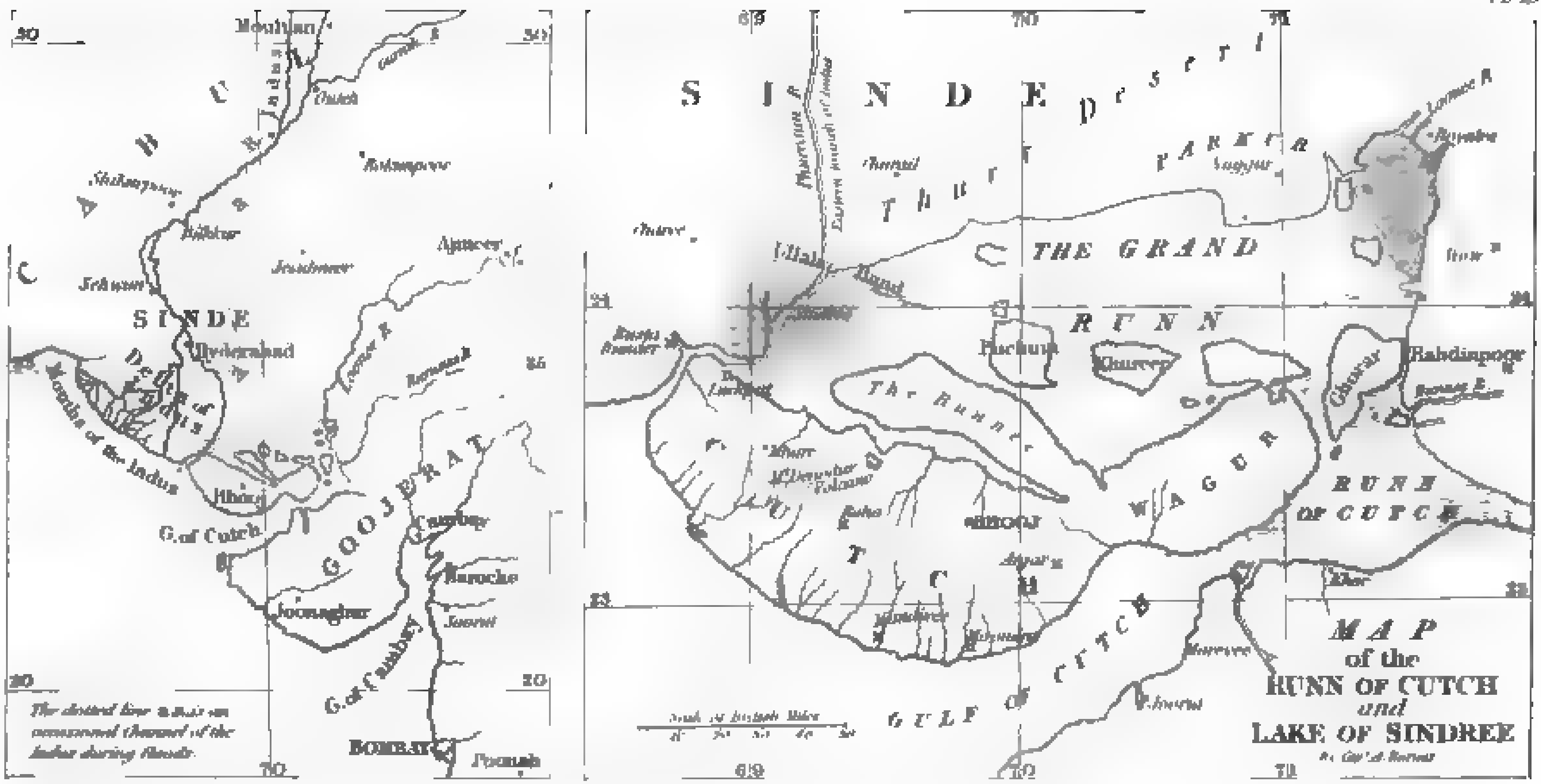
Aleppo, 1822.—*Ionian Isles*, 1820.—When Aleppo was destroyed by an earthquake in 1822, two rocks are reported to have risen from the sea near the island of Cyprus*; and a new rocky island was observed in 1820, not far from the coast of Santa Maura, one of the Ionian Islands, after violent earthquakes.†

Cutch, 1819.—A violent earthquake occurred at Cutch, in the delta of the Indus, on the 16th of June, 1819. (See Map, plate 10.) The principal town, Bhooj, was converted into a heap of ruins, and its stone buildings were thrown down. The shock extended to Ahmedabad, where it was very destructive;

* Journ. of Sci. vol. xiv. p. 450.

† Von Hoff, vol. ii. p. 180.

Pl. III


MAP
of the
RUNN OF CUTCH
and
LAKE OF SINDREE
SINDE
THE GRAND
RUNN
WAGUR
RUNN OF CUTCH
GULF OF CUTCH
GOOJERAT
Moultan
Hyderabad
Bhooj
Bombay
Mouths of the Indus
G. of Cutch
G. of Cambay
The dotted line marks an occasional channel of the Indus during floods.

Sindree on the Eastern branch of the Indus

AS SUBMERGED BY THE EARTHQUAKE OF 1819

From a sketch taken on the spot by Capt. Grindlay in 1838

and at Poonah, four hundred miles farther, it was feebly felt. At the former city, the great mosque erected by Sultan Ahmed nearly 450 years before, fell to the ground, attesting how long a period had elapsed since a shock of similar violence had visited that point. At Anjar, the fort, with its tower and guns, were hurled to the ground in one common mass of ruin. The shocks continued some days until the 20th; when, thirty miles north-west from Bhooj, the volcano called Denodur is said to have burst out in eruption, and the convulsions ceased.

Subsidence in the delta of the Indus.—Although the ruin of towns was great, the face of nature in the inland country, says Captain Macmurdo, was not visibly altered. In the hills some large masses only of rock and soil were detached from the precipices; but the eastern and almost deserted channel of the Indus, which bounds the province of Cutch, was greatly changed. This estuary, or inlet of the sea, was, before the earthquake, fordable at Luckput, being only about a foot deep when the tide was at ebb, and at flood tide never more than six feet; but it was deepened at the fort of Luckput, after the shock, to more than *eighteen feet at low water.** On sounding other parts of the channel, it was found, that where previously the depth of the water at flood never exceeded one or two feet, it had become from four to ten feet deep. By these and other remarkable changes of level, a part of the inland navigation of that country, which had been closed for centuries, became again practicable.

Fort and village submerged.†—The fort and village

* Macmurdo, Ed. Phil. Journ. vol. iv. p. 106.

† I am indebted to Captain (now Col. Sir A.) Burnes for the accompanying engraving (Plate XI.) of the Fort of Sindree,

of Sindree, on the eastern arm of the Indus, above Luckput, are stated by the same writer to have been overflowed; and, after the shock, the tops of the houses and wall were alone to be seen above the water, for the houses, although submerged, were not cast down. Had they been situated, therefore, in the interior, where so many forts were levelled to the ground, their site would, perhaps, have been regarded as having remained comparatively unmoved. Hence we may suspect that great permanent upheavings and depressions of soil may be the result of earthquakes, without the inhabitants being in the least degree conscious of any change of level.

A more recent survey of Cutch by Capt. A. Burnes, who was not in communication with Capt. Macmurdo, confirms the facts above enumerated, and adds many important details.* That officer examined the delta of the Indus in 1826 and 1828, and from his account it appears that, when Sindree subsided in June, 1819, the sea flowed in by the eastern mouth of the Indus, and in a few hours converted a tract of land, 2000 square miles in area, into an inland sea, or lagoon. Neither the rush of the sea into this new depression, nor the movement of the earthquake, threw down entirely the small fort of Sindree, one of the four

as it appeared eleven years before the earthquake; but I am assured by Captain Grant, and others well acquainted with the scene, that the land introduced by the artist in the back-ground is ideal. The flat plain of the Runn could alone be seen in that direction as far as the eye can reach. The mirage so common there may have caused the apparent inequalities which have been introduced as rising ground into the sketch.

* This Memoir is now in the Library of the Royal Asiatic Society of London.

towers, the north-western, still continuing to stand; and the day after the earthquake, the inhabitants, who had ascended to the top of this tower, saved themselves in boats.*

Elevation of the Ullah Bund.—Immediately after the shock, the inhabitants of Sindree saw, at the distance of five miles and a half from their village, a long elevated mound, where previously there had been a low and perfectly level plain. (See Map. pl. 10.) To this uplifted tract they gave the name of "Ullah Bund," or the "Mound of God," to distinguish it from several artificial dams previously thrown across the eastern arm of the Indus.

Extent of country raised.—It has been already ascertained that this new-raised country is *upwards of fifty miles* in length from east to west, running parallel to that line of subsidence before mentioned which caused the grounds around Sindree to be flooded. The range of this elevation extends from Puchum Island towards Gharee; its breadth from north to south is conjectured to be in some parts *sixteen miles*, and its greatest ascertained height above the original level of the delta is ten feet,—an elevation which appears to the eye to be very uniform throughout.

For several years after the convulsion of 1819, the course of the Indus was very unsettled, and at length, in 1826, the river threw a vast body of water into its eastern arm, that called the Phurraun, above Sindree; and forcing its way in a more direct course to the sea, burst through all the artificial dams which had been thrown across its channel, and at length cut right

* I have been enabled, from personal communication with Captain Burnes, to add several particulars to my former account of this earthquake.

through the "Ullah Bund," whereby a natural section was obtained. In the perpendicular cliffs thus laid open, Captain Burnes found that the upraised lands consisted of clay filled with shells. The new channel of the river where it intersected the "bund," was eighteen feet deep, and forty yards in width; but in 1828 the channel was still further enlarged. The Indus, when it first opened this new passage, threw such a body of water into the new mere, or salt lagoon, of Sindree, that it became fresh for many months; but it had recovered its saltness in 1828, when the supply of river-water was less copious, and finally it became more salt than the sea, in consequence, as the natives suggested to Captain Burnes, of the saline particles with which the "Runn of Cutch" is impregnated.

In 1828 Captain Burnes went in a boat to the ruins of Sindree, where a single remaining tower was seen in the midst of a wide expanse of sea. The tops of the ruined walls still rose two or three feet above the level of the water; and standing on one of these, he could behold nothing in the horizon but water, except in one direction, where a blue streak of land to the north indicated the Ullah Bund. This scene presents to the imagination a lively picture of the revolutions now in progress on the earth — a waste of waters where a few years before all was land, and the only land visible consisting of ground uplifted by a recent earthquake.

Ten years after the visit of Captain Burnes above alluded to, my friend, Captain Grant, F. G. S. of the Bombay Engineers, had the kindness to send at my request a native surveyor to make a plan of Sindree and Ullah Bund, in March, 1838. From his description it appears that, at that season, the driest of the

whole year, he found the channel traversing the Bund to be 100 yards wide, without water, and encrusted with salt. He was told that it has now only four or five feet of water in it after rains. The sides or banks were nearly perpendicular, and nine feet in height. The lagoon has diminished both in area and depth, and part near the fort was dry land. The annexed drawing, made by Captain Grant from the surveyor's plan,

Fig 53.

View of the Fort of Sindree, from the west, in March, 1838.

shows the appearance of the fort in the midst of the lake, as seen in 1838 from the west, or from the same point as that from which Captain Grindley's sketch (See Plate XI.) was taken in 1808, before the earthquake.

The Runn of Cutch is a flat region of a very peculiar character, and no less than 7000 square miles in area: a greater superficial extent than Yorkshire, or about one fourth the area of Ireland. It is not a desert of moving sand, nor a marsh, but evidently the dried-up bed of an inland sea, which for a great part of every year has a hard and dry bottom uncovered by weeds or grass, and only supporting here and there

a few tamarisks. But during the monsoons, when the sea runs high, the salt-water driven up from the Gulf of Cutch and the creeks at Luckput overflows a large part of the Runn, especially after rains, when the soaked ground permits the sea-water to spread rapidly. The Runn is also liable to be overflowed occasionally in some parts by river-water: and it is remarkable that the only portion which was ever highly cultivated (that anciently called Sayra) is now permanently submerged. The surface of the Runn is sometimes encrusted with salt about an inch in depth, in consequence of the evaporation of the sea-water. Islands rise up in some parts of the waste, and the boundary lands form bays and promontories. The natives have various traditions respecting the former separation of Cutch and Sinde by a bay of the sea, and the drying up of the district called the Runn. But these tales, besides the usual uncertainty of oral tradition, are farther obscured by mythological fictions. The conversion of the Runn into land is chiefly ascribed to the miraculous powers of a Hindoo saint, by name Damorath (or Dhoorunnath), who had previously done penance for twelve years on the summit of Denodur hill. Captain Grant infers, on various grounds, that this saint flourished about the eleventh or twelfth century of our era. In proof of the drying up of the Runn, some towns far inland are still pointed out as having once been ancient ports. It has, moreover, been always said that ships were wrecked and engulphed by the great catastrophe; and in the jets of black muddy water thrown out of fissures in that region, in 1819, there were cast up numerous pieces of wrought iron and ship nails.* Cones of sand six or eight feet in

* Capt. Burnes's Account.

height were at the same time thrown up on these lands.*

We must not conclude without alluding to a *moral* phenomenon connected with this tremendous catastrophe, which we regard as highly deserving the attention of geologists. It is stated by Capain Burnes, that "these wonderful events passed *unheeded* by the inhabitants of Cutch;" for the region convulsed, though once fertile, had for a long period been reduced to sterility by want of irrigation, so that the natives were indifferent as to its fate. Now it is to this profound apathy which all but highly civilized nations feel, in regard to physical events not having an immediate influence on their worldly fortunes, that we must ascribe the extraordinary dearth of historical information concerning changes of the earth's surface, which modern observations show to be by no means of rare occurrence in the ordinary course of nature.

To the east of the line of this earthquake lies Oojain (called Ozene in the *Periplus Maris Erythr.*). Ruins of an ancient city are there found, a mile north of the present, buried in the earth to the depth of from fifteen to sixteen feet, which inhumation is known to have been the consequence of a tremendous catastrophe in the time of the Rajah Vicramaditya.†

Island of Sumbawa, 1815.—In April, 1815, one of the most frightful eruptions recorded in history occurred in the province of Tomboro, in the island of Sumbawa, about 200 miles from the eastern extremity of Java. In the April of the year preceding the volcano had been observed in a state of considerable activity,

* Capt. Macmurdo's Memoir, Ed. Phil. Journ. vol. iv. p. 106.

† Von Hoff, vol. ii. p. 454.; for further particulars, see book iii. chap. xiii.

ashes having fallen upon the decks of vessels which sailed past the coast.* The eruption of 1815 began on the 5th of April, but was most violent on the 11th and 12th, and did not entirely cease till July. The sound of the explosions was heard in Sumatra, at the distance of 970 geographical miles in a direct line; and at Ternate, in an opposite direction, at the distance of 720 miles. Out of a population of 12,000, in the province of Tomboro, only twenty-six individuals survived. Violent whirlwinds carried up men, horses, cattle, and whatever else came within their influence, into the air; tore up the largest trees by the roots, and covered the whole sea with floating timber.† Great tracts of land were covered by lava, several streams of which, issuing from the crater of the Tomboro mountain, reached the sea. So heavy was the fall of ashes, that they broke into the Resident's house at Bima, forty miles east of the volcano, and rendered it, as well as many other dwellings in the town, uninhabitable. On the side of Java the ashes were carried to the distance of 300 miles, and 217 towards Celebes, in sufficient quantity to darken the air. The floating cinders to the westward of Sumatra formed, on the 12th of April, a mass two feet thick, and several miles in extent, through which ships with difficulty forced their way.

The darkness occasioned in the daytime by the ashes in Java was so profound, that nothing equal to it was ever witnessed in the darkest night. Although this volcanic dust when it fell was an impalpable powder, it was of considerable weight when compressed, a pint of it weighing twelve ounces and three quarters.

* MS. of J. Crawfurd, Esq.

† Raffles's Java, vol. i. p. 28.

"Some of the finest particles," says Mr. Crawfurd, "were transported to the islands of Amboyna and Banda, which last is about 800 miles east from the site of the volcano, although the south-east monsoon was then at its height." They must have been projected, therefore, into the upper regions of the atmosphere, where a counter current prevailed.

Along the sea-coast of Sumbawa, and the adjacent isles, the sea rose suddenly to the height of from two to twelve feet, a great wave rushing up the estuaries, and then suddenly subsiding. Although the wind at Bima was still during the whole time, the sea rolled in upon the shore, and filled the lower parts of the houses with water a foot deep. Every prow and boat was forced from the anchorage, and driven on shore.

The town called Tomboro, on the west side of Sumbawa, was overflowed by the sea, which encroached upon the shore so that the water remained permanently eighteen feet deep in places where there was land before. Here we may observe, that the amount of subsidence of land was apparent, in spite of the ashes, which would naturally have caused the limits of the coast to be extended.

The area over which tremulous noises and other volcanic effects extended, was 1000 English miles in circumference, including the whole of the Molucca Islands, Java, a considerable portion of Celebes, Sumatra, and Borneo. In the island of Amboyna, in the same month and year, the ground opened, threw out water, and then closed again.*

In conclusion, I may remind the reader, that but for

* Raffles's Hist. of Java, vol. i. p. 25. — Ed. Phil. Journ. vol. iii. p. 389.

the accidental presence of Sir Stamford Raffles, then governor of Java, we should scarcely have heard in Europe of this tremendous catastrophe. He required all the residents in the various districts under his authority to send in a statement of the circumstances which occurred within their own knowledge; but, valuable as were their communications, they are often calculated to excite rather than to satisfy the curiosity of the geologist. They mention, that similar effects, though in a less degree, had, about seven years before, accompanied an eruption of Carang Assam, a volcano in the island of Bali, west of Sumatra; but no particulars of that great catastrophe are recorded.*

Caraccas, 1812.—On the 26th of March, 1812, several violent shocks of an earthquake were felt in Caraccas. The surface undulated like a boiling liquid, and terrific sounds were heard underground. The whole city with its splendid churches was in an instant a heap of ruins, under which 10,000 of the inhabitants were buried. On the 5th of April, enormous rocks were detached from the mountains. It was believed that the mountain Silla lost from 300 to 360 feet of its height by subsidence; but this was an opinion not founded on any measurement. On the 27th of April, a volcano in St. Vincent's threw out ashes; and on the 30th, lava flowed from its crater into the sea, while its explosions were heard at a distance equal to that between Vesuvius and Switzerland, the sound being transmitted, as Humboldt supposes, through the ground. During the earthquake which destroyed Caraccas, an immense quantity of water was thrown out at Valecillo, near Valencia, as also at Porto Cabello,

* Life and Services of Sir Stamford Raffles, p. 241. London, 1830.

through openings in the earth; and in the Lake Maracaybo the water sank. Humboldt observed that the Cordilleras, composed of gneiss and mica slate, and the country immediately at their foot, were more violently shaken than the plains.*

South Carolina, 1811. — *New Madrid.* — Previous to the destruction of La Guayra and Caraccas, in 1812, South Carolina was convulsed by earthquakes; and the shocks continued till those cities were destroyed. The valley also of the Mississippi, from the village of New Madrid to the mouth of the Ohio in one direction, and to the St. Francis in another, was convulsed to such a degree as to create lakes and islands. Flint, the geographer, who visited the country seven years after the event, informs us, that a tract of many miles in extent, near the Little Prairie, became covered with water three or four feet deep; and when the water disappeared, a stratum of sand was left in its place. Large lakes of twenty miles in extent were formed in the course of an hour, and others were drained. The grave yard at New Madrid was precipitated into the bed of the Mississippi; and it is stated that the ground whereon the town is built, and the river bank for fifteen miles above, sank eight feet below their former level.† The neighbouring forest presented for some years afterwards "a singular scene of confusion; the trees standing inclined in every direction, and many having their trunks and branches broken."‡

The inhabitants relate that the earth rose in great undulations; and when these reached a certain fearful

* Humboldt's Pers. Nar. vol. iv. p. 12; and Ed. Phil. Journ. vol. i. p. 272., 1819.

† Cramer's Navigator, p. 243. Pittsburgh, 1821.

‡ Long's Exped. to the Rocky Mountains, vol. iii. p. 184.

height, the soil burst, and vast volumes of water, sand, and pit-coal were discharged as high as the tops of the trees. Flint saw hundreds of these deep chasms remaining in an alluvial soil, seven years after. The people in the country, although inexperienced in such convulsions, had remarked that the chasms in the earth were in a direction from S.W. to N.E.; and they accordingly felled the tallest trees; and laying them at right angles to the chasms, stationed themselves upon them. By this invention, when chasms opened more than once under these trees, several persons were prevented from being swallowed up.* At one period during this earthquake, the ground not far below New Madrid swelled up so as to arrest the Mississippi in its course, and to cause a temporary reflux of its waves. The motion of some of the shocks was horizontal, and of others perpendicular; and the vertical movement is said to have been much less desolating than the horizontal. If this be often the case, those shocks which injure cities least may produce the greatest alteration of level.

Aleutian Islands, 1806. — In the year 1806, a new island, in the form of a peak, with some low conical hills upon it, rose from the sea among the Aleutian Islands, east of Kamtschatka. According to Langsdorf †, it was four geographical miles in circumference; and Von Buch infers, from its magnitude, and from its not having again subsided below the level of the sea, that it did not consist merely of ejected matter, but of a solid rock of trachyte upheaved.‡ Another extraordinary eruption happened in the spring of the year

* Silliman's Journ., Jan. 1829.

† Bemerkungen auf einer Reise um die Welt. bd. ii. s. 209.

‡ Neue Allgem. Geogr. Ephemer. bd. iii. s. 348.

1814, in the sea near Unalaschka, in the same archipelago. A new isle was then produced of considerable size, and with a peak three thousand feet high, which remained standing for a year afterwards, though with somewhat diminished height.

Although it is not improbable that earthquakes accompanying these tremendous eruptions may have heaved up part of the bed of the sea, yet the circumstance of the islands not having disappeared like Sabrina (see p. 226) may have arisen from the emission of lava. If Jorullo, for example, in 1759, had risen from a shallow sea to the height of 1600 feet, instead of attaining that elevation above the Mexican plateau, the massive current of basaltic lava which poured out from its crater would have enabled it to withstand, for a long period, the action of a turbulent sea.

Reflections on the earthquakes of the nineteenth century. — We are now about to pass on to the events of the eighteenth century; but, before we leave the consideration of those already enumerated, let us pause for a moment, and reflect how many remarkable facts of geological interest are afforded by the earthquakes above described, though they constitute but a small part of the convulsions even of the last forty years. New rocks have risen from the waters; new hot springs have burst out, and the temperature of another has been raised; the coast of Chili has been thrice permanently elevated; a considerable tract in the delta of the Indus has sunk down, and some of its shallow channels have become navigable; an adjoining part of the same district, upwards of fifty miles in length and sixteen in breadth, has been raised about ten feet above its former level; the town of Tomboro has been submerged, and twelve

thousand of the inhabitants of Sumbawa have been destroyed. Yet, with a knowledge of these terrific catastrophes, witnessed during so brief a period by the present generation, will the geologist declare with perfect composure that the earth has at length settled into a state of repose? Will he continue to assert that the changes of relative level of land and sea, so common in former ages of the world, have now ceased? If, in the face of so many striking facts, he persists in maintaining this favourite dogma, it is in vain to hope that, by accumulating the proofs of similar convulsions during a series of antecedent ages, we shall shake his tenacity of purpose: —

> Si fractus illabatur orbis
> Impavidum ferient ruinæ.

EARTHQUAKES OF THE EIGHTEENTH CENTURY.

Quito, 1797. — On the morning of February 4th, 1797, the volcano of Tunguragua in Quito, and the surrounding district, for forty leagues from south to north, and twenty leagues from west to east, experienced an undulating movement, which lasted four minutes. The same shock was felt over a tract of 170 leagues from south to north, from Piura to Popayan; and 140 from west to east, from the sea to the river Napo. In the smaller district first mentioned, where the movement was more intense, every town was levelled to the ground; and Riobamba, Quero, and other places, were buried under masses detached from the mountains. At the foot of Tunguragua the earth was rent open in several places; and streams of water and fetid mud, called "moya," poured out, overflowing and wasting every thing. In

valleys one thousand feet broad, the water of these floods reached to the height of six hundred feet: and the mud deposit barred up the course of the river, so as to form lakes, which in some places continued for more than eighty days. Flames and suffocating vapours escaped from the lake Quilotoa, and killed all the cattle on its shores. The shocks continued all February and March; and on the fifth of April they recurred with almost as much violence as at first. We are told that the form of the surface in the district most shaken was entirely altered, but no exact measurements are given whereby we may estimate the degree of elevation or subsidence.* Indeed it would be difficult, except in the immediate neighbourhood of the sea, to obtain any certain standard of comparison, if the levels were really as much altered as the narrations imply.

Cumana, 1797.—In the same year, on the 14th of December, the small Antilles experienced subterranean movements, and four-fifths of the town of Cumana was shaken down by a vertical shock. The form of the shoal of Mornerouge, at the mouth of the river Bourdones, was changed by an upheaving of the ground.†

Quebec, 1791.—We learn from Captain Bayfield's memoirs, that earthquakes are very frequent on the shore of the estuary of the St. Lawrence, of force sufficient at times to split walls and throw down chimneys. Such were the effects experienced in December, 1791, in St. Paul's Bay, about fifty miles N.E. from Quebec; and the inhabitants say, that about every

* Cavanilles, Journ. de Phys. tome xlix. p. 230. Gilbert's Annalen, bd. vi. p. 67. Humboldt's Voy. p. 317.

† Humboldt's Voy., Relat. Hist., part i. p. 309.

twenty-five years a violent earthquake returns, which lasts forty days. In the History of Canada, it is stated, that, in 1663, a tremendous convulsion lasted six months, extending from Quebec to Tadeausac,—a distance of about 130 miles. The ice on the river was broken up, and many landslips caused.*

Caraccas, 1790.—In the Caraccas, near where the Caura joins the Orinoco, between the towns San Pedro de Alcantara and San Francisco de Aripao, an earthquake, on St. Matthew's day, 1790, caused a sinking in of the granitic soil, and left a lake eight hundred yards in diameter, and from eighty to one hundred in depth. It was a portion of the forest of Aripao which subsided, and the trees remained green for several months under water.†

Sicily, 1790.—On the 18th of March in the same year, at S. Maria di Niscemi, some miles from Terranuova, near the south coast of Sicily, the ground gradually sank down for a circumference of three Italian miles, during seven shocks; and, in one place, to the depth of thirty feet. It continued to subside to the end of the month. Several fissures sent forth sulphur, petroleum, steam, and hot water; and a stream of mud, which flowed for two hours, and covered a space sixty feet long, and thirty broad. This happened far from both the ancient and modern volcanic district, in a group of strata consisting chiefly of blue clay.‡

Java, 1786.—About the year 1786, an earthquake was felt at intervals, for the period of four months, in the neighbourhood of Batur, in Java, and an eruption followed. Various rents were formed, which emitted

* Macgregor's Travels in America.

† Humboldt's Voy., Relat. Hist., part ii. p. 632.

‡ Ferrara, Camp. fl., p. 51.

a sulphureous vapour; separate tracts sunk away, and were swallowed by the earth. Into one of these the rivulet Dotog entered, and afterwards continued to follow a subterraneous course. The village of Jampang was buried in the ground, with thirty-eight of its inhabitants, who had not time to escape. We are indebted to Dr. Horsfield for having verified the above-mentioned facts.*

Japan Isles, 1783.—In the province of Sinano, in the isle of Nifon, the volcanic mountain of Asamayama, situated north-east of the town of Komoro, was in violent eruption August 1. 1783. The waters of several rivers are said to have boiled, and one of the largest of them, Yone-garva, deluged the country. The eruption was preceded by a frightful earthquake; gulphs are said to have opened every where, and many towns to have been swallowed up, while others were subsequently buried by lava.†

* Batav. Trans. vol. viii. p. 141.

† Humboldt, Fragmens Asiatiques, &c. tom. i. p. 229.

CHAPTER XVI.

EARTHQUAKE IN CALABRIA, 1783.

Earthquake in Calabria, February 5. 1783 — Shocks continued to the end of the year 1786 — Authorities — Area convulsed — Geological structure of the district — Difficulty of ascertaining changes of level — Subsidence of the quay at Messina — Shift or fault in the Round Tower of Terranuova — Movement in the stones of two obelisks — Opening and closing of fissures — Large edifices engulphed — Dimensions of new caverns and fissures — Gradual closing in of rents — Bounding of detached masses into the air — Landslips — Buildings transported entire to great distances — New lakes — Currents of mud — Funnel-shaped hollows in alluvial plains — Fall of cliffs, and shore near Scilla inundated — State of Stromboli and Etna during the shocks — How earthquakes contribute to the formation of valleys — Concluding remarks.

Calabria, 1783.— Of the numerous earthquakes which have occurred in different parts of the globe, during the last hundred years, that of Calabria, in 1783, is almost the only one of which the geologist can be said to have such a circumstantial account as to enable him fully to appreciate the changes which this cause is capable of producing in the lapse of ages. The shocks began in February, 1783, and lasted for nearly four years, to the end of 1786. Neither in duration, nor in violence, nor in the extent of territory moved, was this convulsion remarkable, when contrasted with many experienced in other countries,

both during the last and present century; nor were the alterations which it occasioned in the relative level of hill and valley, land and sea, so great as those affected by some subterranean movements in South America, in later times. The importance of the earthquake in question arises from the circumstance, that Calabria is the only spot hitherto visited, both during and after the convulsions, by men possessing sufficient leisure, zeal, and scientific information, to enable them to collect and describe with accuracy the physical facts which throw light on geological questions.

Fig. 54.

Authorities — Among the numerous authorities, Vivenzio, physician to the King of Naples, transmitted to the court a regular statement of his observations during the continuance of the shocks; and his narrative is drawn up with care and clearness.* Francesco Antonio Grimaldi, then secretary of war, visited the different provinces at the king's command, and published a most detailed description of the permanent changes in the surface.† He measured the length, breadth, and depth of the different fissures and gulphs which opened, and ascertained their number in many provinces. His comments, moreover, on the reports of the inhabitants, and his explanations of their relations, are judicious and instructive. Pignataro, a physician residing at Monteleone, a town placed in the very centre of the convulsions, kept a register of the shocks, distinguishing them into four classes, according to their degree of violence. From his work, it appears that, in the year 1783, the number was 949, of which 501 were shocks of the first degree of force; and in the following year there were 151, of which 98 were of the first magnitude.

Count Ippolito, also, and many others, wrote descriptions of the earthquake; and the Royal Academy of Naples, not satisfied with these and other observations, sent a deputation from their own body into Calabria, before the shocks had ceased, who were accompanied by artists instructed to illustrate by drawings the physical changes of the district, and the state of ruined towns and edifices. Unfortunately these artists were not very successful in their representations of the

* Istoria de' Tremuoti della Calabria del 1783.

† Descriz. de' Tremuoti Accad. nelle Calabria nel 1783. Napoli, 1784.

condition of the country, particularly when they attempted to express, on a large scale, the extraordinary revolutions which many of the great and minor river-courses underwent. But many of the plates published by the Academy are valuable; and as they are little known, I shall frequently avail myself of them to illustrate the facts about to be described.*

In addition to these Neapolitan sources of information, our countryman, Sir William Hamilton, surveyed the district, not without some personal risk, before the shocks had ceased; and his sketch, published in the Philosophical Transactions, supplies many facts that would otherwise have been lost. He has explained, in a rational manner, many events which, as related in the language of some eye-witnesses, appeared marvellous and incredible. Dolomieu also examined Calabria during the catastrophe, and wrote an account of the earthquake, correcting a mistake into which Hamilton had fallen, who supposed that a part of the tract shaken had consisted of volcanic tuff. It is, indeed, a circumstance which enhances the geological interest of the commotions which so often modify the surface of Calabria, that they are confined to a country where there are neither ancient nor modern rocks of volcanic or trappean origin; so that at some future time, when the era of disturbance shall have passed by, the cause of former revolutions will be as latent as in parts of Great Britain now occupied exclusively by ancient marine formations.

Extent of the area convulsed.—The convulsion of the earth, sea, and air extended over the whole of

* Istoria de' Fenomeni del Tremoto, &c. nell' An. 1783, posta in luce dalla Real. Accad., &c. di Nap. Napoli, 1788. fol.

Calabria Ultra, the south-east part of Calabria Citra, and across the sea to Messina and its environs; a district lying between the 38th and 39th degrees of latitude. The concussion was perceptible over a great part of Sicily, and as far north as Naples; but the surface over which the shocks acted so forcibly as to excite intense alarm did not generally exceed five hundred square miles in area. The soil of that part of Calabria is composed chiefly, like the southern part of Sicily, of calcareo-argillaceous strata of great thickness, containing marine shells. This clay is sometimes associated with beds of sand and limestone. For the most part these formations resemble in appearance and consistency the Subapennine marls, with their accompanying sands and sandstones; and the whole group bears considerable resemblance, in the yielding nature of its materials, to most of our tertiary deposits in France and England. Chronologically considered, however, the Calabrian formations are comparatively of very modern date, and abound in fossil shells referrible to species now living in the Mediterranean.

We learn from Vivenzio that, on the 20th and 26th of March, 1783, earthquakes occurred in the islands of Zante, Cephalonia, and St. Maura; and in the last-mentioned island several public edifices and private houses were overthrown, and many people destroyed. It has been already shown that the Ionian Islands fall within the line of the same great volcanic region as Calabria; so that both earthquakes were probably derived from a common source, and it is not improbable that the bed of the whole intermediate sea was convulsed.

If the city of Oppido, in Calabria Ultra, be taken as a centre, and round that centre a circle be described, with a radius of twenty-two miles, this space will com-

prehend the surface of the country which suffered the greatest alteration, and where all the towns and villages were destroyed. The first shock, of February 5th, 1783, threw down, in two minutes, the greater part of the houses in all the cities, towns, and villages, from the western flanks of the Apennines in Calabria Ultra to Messina in Sicily, and convulsed the whole surface of the country. Another occurred on the 28th of March, with almost equal violence. The granitic chain which passes through Calabria from north to south, and attains the height of many thousand feet, was shaken but slightly by the first shock, but more rudely by some which followed.

Some writers have asserted that the wave-like movements which were propagated through the recent strata, from west to east, became very violent when they reached the point of junction with the granite, as if a reaction was produced where the undulatory movement of the soft strata was suddenly arrested by the more solid rocks. But the statement of Dolomieu on this subject is most interesting, and, perhaps, in a geological point of view, the most important of all the observations which are recorded.*

The Apennines, he says, which consist in great part of hard and solid granite, with some micaceous and argillaceous schists, form bare mountains with steep sides, and exhibit marks of great degradation. At their base newer strata are seen of sand and clay, mingled with shells; a marine deposit containing such ingredients as would result from the decomposition of granite. The surface of this newer (*tertiary*) formation constitutes what is called the plain of Calabria — a platform

* Dissertation on the Calabrian Earthquake, &c., translated in Pinkerton's Voyages and Travels, vol. v.

which is flat and level, except where intersected by narrow valleys or ravines, which rivers and torrents have excavated sometimes to the depth of six hundred feet. The sides of these ravines are almost perpendicular; for the superior stratum, being bound together by the roots of trees, prevents the formation of a sloping bank. The usual effect of the earthquake, he continues, was to disconnect all those masses which either had not sufficient bases for their bulk, or which were supported only by lateral adherence. Hence it follows that throughout almost the whole length of the chain the soil which adhered to the granite at the base of the mountains Caulone, Esope, Sagra, and Aspramonte, slid over the solid and steeply inclined nucleus, and descended somewhat lower, leaving almost uninterruptedly from St. George to beyond St. Christina, a distance of from nine to ten miles, a chasm between the solid granitic nucleus and the sandy soil. Many lands slipping thus were carried to a considerable distance from their former position, so as entirely to cover others; and disputes arose as to whom the property which had thus shifted its place should belong.

From this account of Dolomieu we might anticipate, as the result of a continuance of such earthquakes, first, a longitudinal valley following the line of junction of the older and newer rocks; secondly, greater disturbance in the newer strata near the point of contact than at a greater distance from the mountains; phenomena very common in other parts of Italy at the junction of the Apennine and Subapennine formations.

The surface of the country often heaved like the billows of a swelling sea, which produced a swimming in the head, like sea-sickness. It is particulary stated,

in almost all the accounts, that just before each shock the clouds appeared motionless; and, although no explanation is offered of this phenomenon, it is obviously the same as that observed in a ship at sea when it pitches violently. The clouds seem arrested in their career as often as the vessel rises in a direction contrary to their course; so that the Calabrians must have experienced precisely the same motion on the land.

Trees, supported by their trunks, sometimes bent during the shocks to the earth, and touched it with their tops. This is mentioned as a well-known fact by Dolomieu; and he assures us that he was always on his guard against the spirit of exaggeration in which the vulgar are ever ready to indulge when relating these wonderful occurrences.

It is impossible to suppose that these waves, which are described in Italy and other regions of earthquakes as passing along the solid surface of the earth in a given direction like a billow on the sea, have any strict analogy with the undulations of a fluid. They are doubtless the effects of vibrations, radiating from some deep-seated point, each of which on reaching the surface lifts up the ground, and then allows it again to subside. As the distance between the source of the subterranean movement and the surface must vary according to the outline of the country, so the vibratory jar will reach different points in succession.

I shall now consider, in the first place, that class of physical changes produced by the earthquake which are connected with alterations in the relative level of the different parts of the land; and afterwards describe those which are more immediately connected with the derangement of the regular drainage of the

country; and where the force of running water cooperated with that of the earthquake.

Difficulty of ascertaining changes of level.—In regard to alterations of relative level, none of the accounts establish that they were on a considerable scale; but it must always be remembered that, in proportion to the area moved is the difficulty of proving that the general level has undergone any change, unless the sea-coast happens to have participated in the principal movement. Even then it is often impossible to determine whether an elevation or depression even of several feet has occurred, because there is nothing to attract notice in a band of shingle and sand of unequal breadth above the level of the sea running parallel to a coast; such bands generally marking the point reached by the waves during spring tides, or the most violent tempests. The scientific investigator has not sufficient topographical knowledge to discover whether the extent of beach has diminished or increased; and he who has the necessary local information scarcely ever feels any interest in ascertaining the amount of the rise or fall of the ground. Add to this the great difficulty of making correct observations, in consequence of the enormous waves which roll in upon a coast during an earthquake, and efface every landmark near the shore.

Subsidence of the quay at Messina.—It is evidently in seaports alone that we can look for very accurate indications of slight changes of level; and when we find them, we may presume that they would not be rare at other points, if equal facilities of comparing relative altitudes were afforded. Grimaldi states (and his account is confirmed by Hamilton and others), that at Messina, in Sicily, the shore was rent; and the soil

along the port, which before the shock was perfectly level, was found afterwards to be inclined towards the sea, — the sea itself near the "Banchina" becoming deeper, and its bottom in several places disordered. The quay also sunk down about fourteen inches below the level of the sea, and the houses in its vicinity were much fissured. (*Phil. Trans.* 1783.)

Among various proofs of partial elevation and depression in the interior, the Academicians mention, in their Survey, that the ground was sometimes on the same level on both sides of new ravines and fissures, but sometimes there had been a considerable shifting, either by the upheaving of one side, or the subsidence of the other. Thus, on the sides of long rents in the territory of Soriano, the stratified masses had altered their relative position to the extent of from eight to fourteen palms (six to ten and a half feet).

Polistena. — Similar shifts in the strata are alluded to in the territory of Polistena, where there appeared

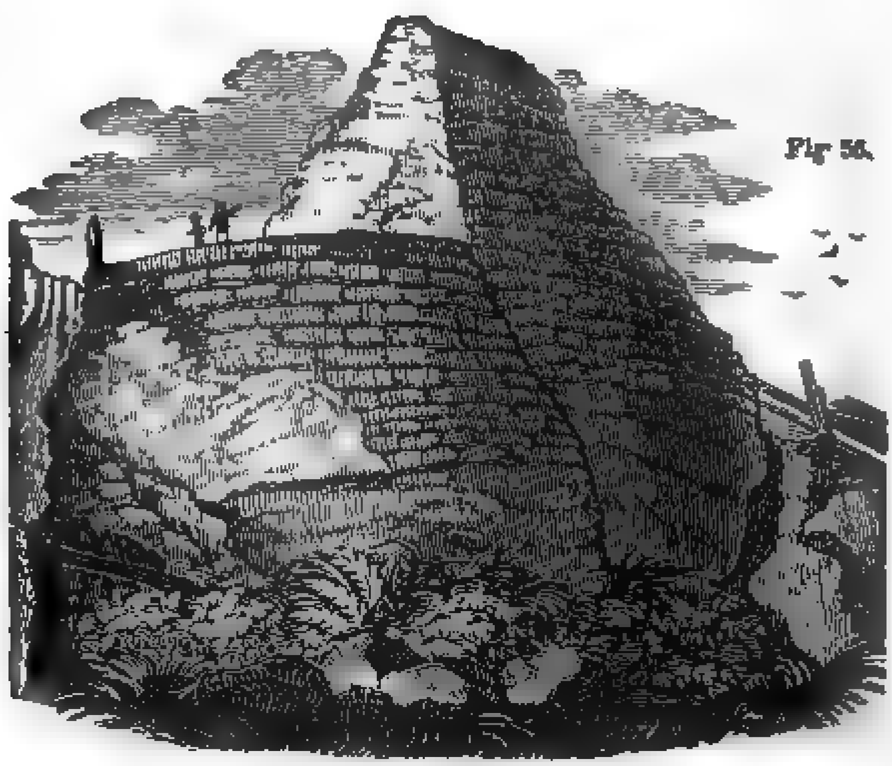
Fig. 55.

Deep fissure, near Polistena, caused by the earthquake of 1783.

innumerable fissures in the earth. One of these was of great length and depth; and in parts the level of the corresponding sides was greatly changed. (See Fig. 55.)

Terranuova. — In the town of Terranuova some houses were seen uplifted above the common level, and others adjoining sunk down into the earth. In several streets the soil appeared thrust up, and abutted against the walls of houses: a large circular tower of solid masonry, part of which had withstood the general destruction, was divided by a vertical rent, and one side was upraised, and the foundations heaved out of the ground. It was compared by the Academicians to a great tooth half extracted from the alveolus, with the upper part of the fangs exposed. (See Fig. 56.)

Fig. 56.



Shift or "fault" in the round tower of Terranuova in Calabria, occasioned by the earthquake of 1783.

Along the line of this shift, or "fault," as it would be termed technically by miners, the walls were found to adhere firmly to each other, and to fit so well, that the only signs of their having been disunited was the want of correspondence in the courses of stone on either side of the rent.

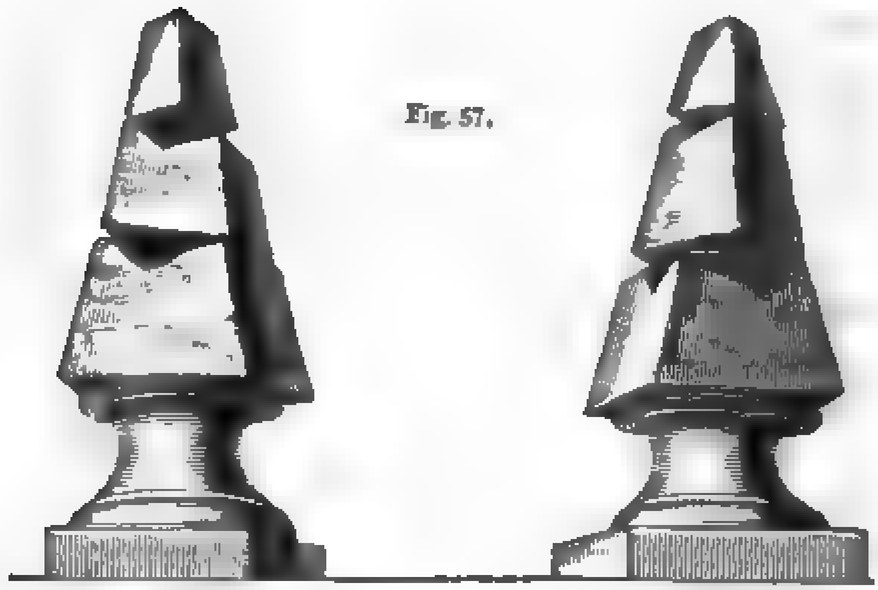
Dolomieu saw a stone well in the convent of the Augustins at Terranuova, which had the appearance of having been driven out of the earth. It resembled a small tower eight or nine feet in height, and a little inclined. This effect, he says, was produced by the consolidation and consequent sinking of the sandy soil in which the well was dug.

In some walls which had been thrown down, or violently shaken, in Monteleone, the separate stones were parted from the mortar, so as to leave an exact mould where they had rested; whereas in other cases the mortar was ground to dust between the stones.

It appears that the wave-like motions, and those which are called vorticose or whirling in a vortex, often produced effects of the most capricious kind. Thus, in some streets of Monteleone, every house was thrown down but one; in others, all but two; and the buildings which were spared were often scarcely in the least degree injured.

In many cities of Calabria, all the most solid buildings were thrown down, while those which were slightly built escaped; but at Rosarno, as also at Messina in Sicily, it was precisely the reverse, the massive edifices being the only ones that stood. Two obelisks (Fig. 57.) placed at the extremities of a magnificent façade in the convent of S. Bruno, in a small town called Stefano del Bosco, were observed to have undergone a movement of a singular kind. The shock

Fig. 57.



Shift in the stones of two obelisks in the Convent of S. Bruno.

which agitated the building is described as having been horizontal and vorticose. The pedestal of each obelisk remained in its original place; but the separate stones above were turned partially round, and removed sometimes nine inches from their position without falling. It has been suggested, however, that this kind of displacement may be due to a vibratory rather than a whirling motion.*

Fissures. — It appears evident that a great part of the rending and fissuring of the ground was the effect of a violent motion from below upwards; and in a multitude of cases where the rents and chasms opened and closed alternately, we must suppose that the earth was by turns heaved up, and then let fall again. We may conceive the same effect to be produced on a small scale, if, by some mechanical force, a pavement composed of large flags of stone should be raised up, and then allowed to fall suddenly, so as to resume its

* Darwin's Journal, p. 376.

original position. If any small pebbles happened to be lying on the line of contact of two flags, they would fall into the opening when the pavement rose, and be swallowed up, so that no trace of them would appear after the subsidence of the stones. In the same manner, when the earth was upheaved, large houses, trees, cattle, and men were engulphed in an instant in chasms and fissures; and when the ground sank down again, the earth closed upon them, so that no vestige of them was discoverable on the surface. In many instances, individuals were swallowed up by one shock, and then thrown out again alive, together with large jets of water, by the shock which immediately succeeded.

At Jerocarne, a country which, according to the Academicians, was *lacerated* in a most extraordinary manner, the fissures ran in every direction "like cracks on a broken pane of glass" (see Fig. 58); and

Fig. 58.

Fissures near Jerocarne, in Calabria, caused by the earthquake of 1783.

as a great portion of them remained open after the shocks, it is very possible that this country was perma-

nently upraised. It was usual, as we learn from Dolomieu, for the chasms and fissures throughout Calabria to run parellel to the course of some pre-existing gorges in their neighbourhood.

Houses engulphed. — In the vicinity of Oppido, the central point from which the earthquake diffused its violent movements, many houses were swallowed up by the yawning earth, which closed immediately over them. In the adjacent district, also, of Cannamaria four farm-houses, several oil-stores, and some spacious dwelling-houses were so completely engulphed in one chasm, that not a vestige of them was afterwards discernible. The same phenomenon occurred at Terranuova, S. Christina, and Sinopoli. The Academicians state particularly, that when deep abysses had opened in the argillaceous strata of Terranuova, and houses had sunk into them, the sides of the chasms closed with such violence, that, on excavating afterwards to recover articles of value, the workmen found the contents and detached parts of the buildings jammed together so as to become one compact mass. It is unnecessary to accumulate examples of similar occurrences; but so many are well authenticated during this earthquake in Calabria, that we may, without hesitation, yield assent to the accounts of catastrophes of the same kind repeated again and again in history, where whole towns are declared to have been engulphed, and nothing but a pool of water or tract of sand left in their place.

Chasm formed near Oppido. — On the sloping side of a hill near Oppido a great chasm opened; and, although a large quantity of soil was precipitated into the abyss, together with a considerable number of olive-trees and part of a vineyard, a great gulph remained after the

shock, in the form of an amphitheatre, 500 feet long and 200 feet deep. (See Fig. 59.)

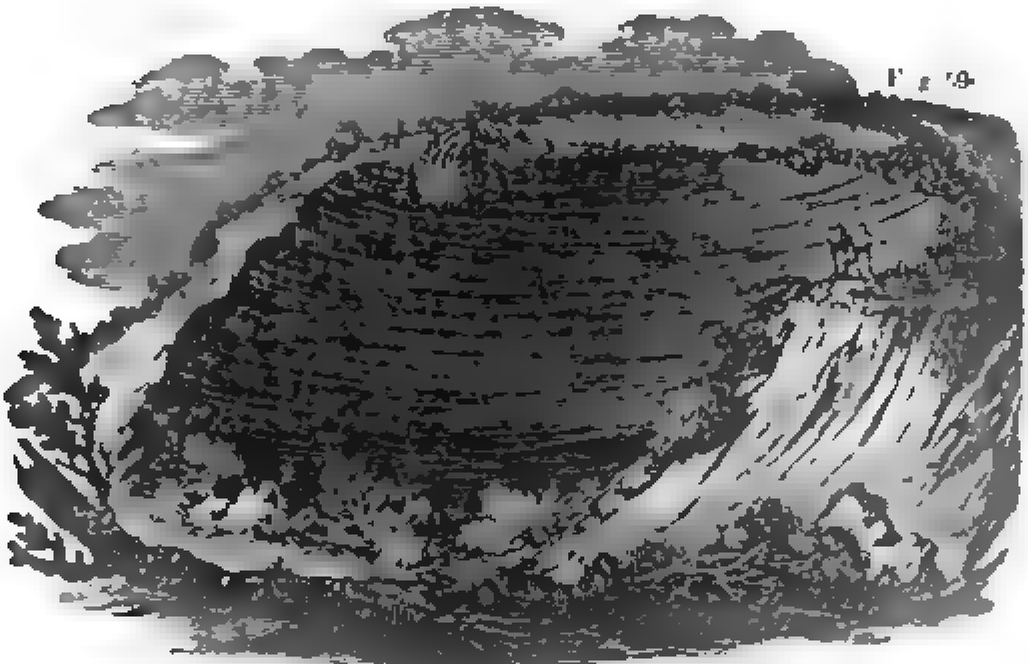


Fig. 59.

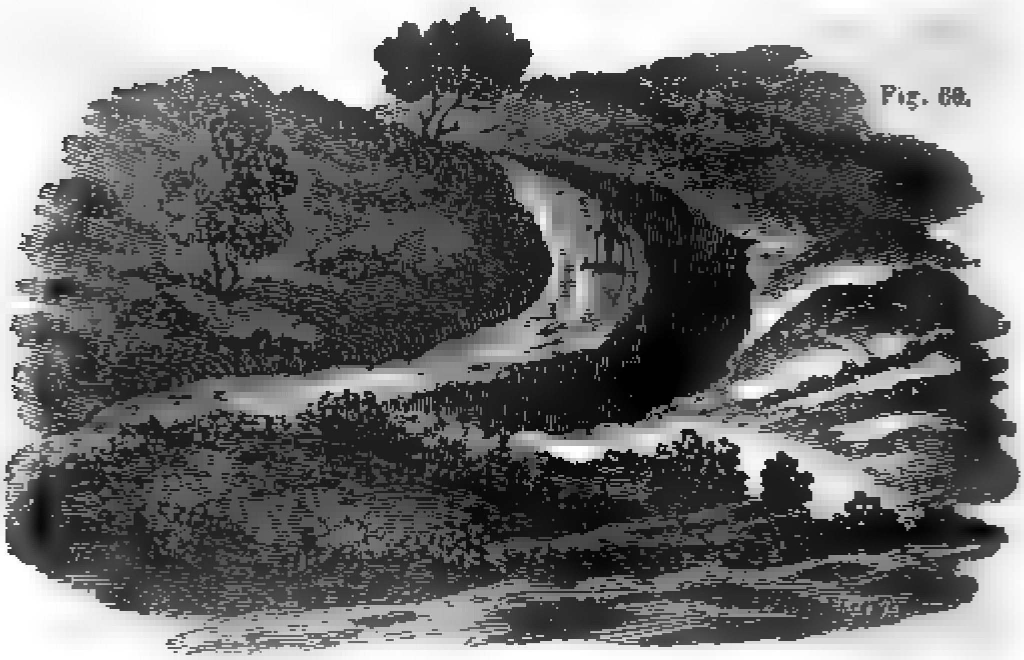
Chasm formed by the earthquake of 1783 near Oppido, in Calabria.

Dimensions of new fissures and chasms. — According to Grimaldi, many fissures and chasms, formed by the first shock of February 5th, were greatly widened, lengthened, and deepened by the violent convulsions of March 28th. In the territory of San Fili this observer found a new ravine, half a mile in length, two feet and a half broad, and twenty-five feet deep; and another of similar dimensions in the territory of Rosarno. A ravine *nearly a mile long*, 105 feet broad, and thirty feet deep, opened in the district of Plaisano, where, also, two gulphs were caused — one in a place called Cerzulle, three quarters of a mile long, 150 feet broad, and above *one hundred feet deep;* and another at La Fortuna, nearly a quarter of a mile long, above thirty feet in breadth, and no less than 225 feet deep.

In the district of Fosolano three gulphs opened;

one of these measured 300 feet square, and above thirty feet deep; another was nearly half a mile long, fifteen feet broad, and above thirty feet deep; the third was 750 feet square. Lastly, a calcareous mountain, called Zefirio, at the southern extremity of the Italian peninsula, was cleft in two for the length of nearly half a mile, and an irregular breadth of many feet. Some of these chasms were in the form of a crescent. The annexed cut (Fig. 60) represents one by no means remarkable for it dimensions, which remained open by the side of a small pass over the hill of St. Angelo, near Soriano. The small river Mesima is seen in the foreground.

Fig. 60.

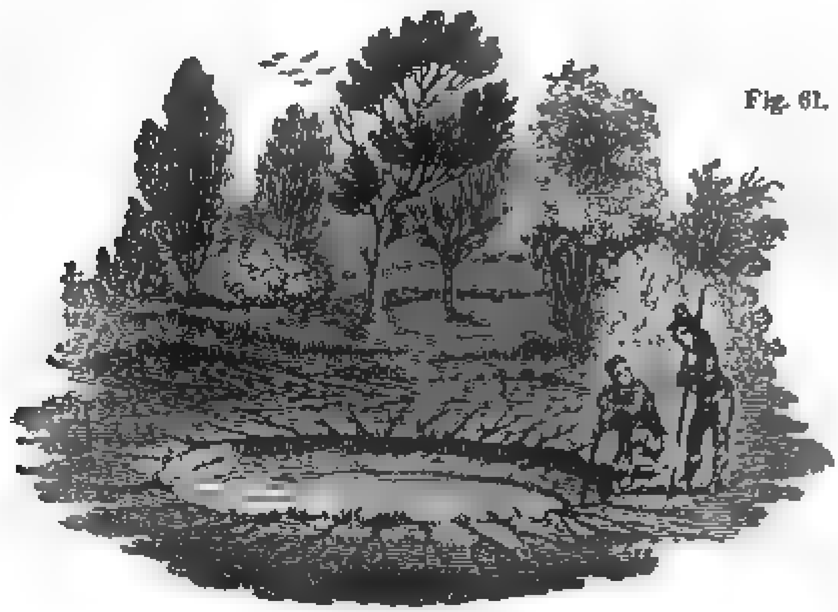


Chasm in the hill of St. Angelo, near Soriano, in Calabria, caused by the earthquake of 1783.

Formation of new lakes. — In the vicinity of Seminara, a lake was suddenly formed by the opening of a great chasm, from the bottom of which water issued. This lake was called Lago del Tolfilo. It extended 1785 feet in length, by 937 in breadth, and 52 in

depth. The inhabitants, dreading the miasma of this stagnant pool, endeavoured, at great cost, to drain it by canals, but without success, as it was fed by springs issuing from the bottom of the deep chasm. A small circular subsidence occurred not far from Polistena, of which a representation is given below.

Fig. 61.



Circular pond near Polistena, in Calabria, caused by the earthquake in 1783.

Gradual closing in of fissures. — Sir W. Hamilton was shown several deep fissures in the vicinity of Mileto, which, although not one of them was above a foot in breadth, had opened so wide during the earthquake as to swallow up an ox and nearly one hundred goats. The Academicians also found, on their return through districts which they had passed at the commencement of their tour, that many rents had, in that short interval, gradually closed in, so that their width had diminished several feet, and the opposite walls had sometimes nearly met. It is natural that this should happen in argillaceous strata, while, in more solid rocks, we may expect that fissures will remain open

for ages. Should this be ascertained to be a general fact in countries convulsed by earthquakes, it may afford a satisfactory explanation of a common phenomenon in mineral veins. Such veins often retain their full size so long as the rocks consist of limestone, granite, or other indurated materials; but they contract their dimensions, become mere threads, or are even entirely cut off, where masses of an argillaceous nature are interposed. If we suppose the filling up of fissures with metallic and other ingredients to be a process requiring ages for its completion, it is obvious that the opposite walls of rents, where strata consist of yielding materials, must collapse or approach very near to each other before sufficient time is allowed for the accretion of a large quantity of veinstone.

Thermal waters augmented. — It is stated by Grimaldi, that the thermal waters of St. Eufemia, in Terra di Amato, which first burst out during the earthquake of 1638, acquired, in February, 1783, an augmentation both in quantity and degree of heat. This fact appears to indicate a connection between the heat of the interior and the fissures caused by the Calabrian earthquakes, notwithstanding the absence of volcanic rocks, either ancient or modern, in that district.

Bounding of detached masses into the air. — The violence of the movement of the ground upwards was singularly illustrated by what the Academicians call the "sbalzo," or bounding into the air, to the height of several yards, of masses slightly adhering to the surface. In some towns, a great part of the pavement stones were thrown up, and found lying with their lower sides uppermost. In these cases, we must suppose that they were propelled upwards by the momen-

tum which they had acquired; and that the adhesion of one end of the mass being greater than that of the other, a rotatory motion had been communicated to them. When the stone was projected to a sufficient height to perform somewhat more than a quarter of a revolution in the air, it pitched down on its edge, and fell with its lower side uppermost.

Effects of earthquakes on the excavation of valleys. — The next class of effects to be considered, are those more immediately connected with the formation of valleys, in which the action of water was often combined with that of the earthquake. The country agitated was composed, as before stated, chiefly of argillaceous strata, intersected by deep narrow valleys, sometimes from 500 to 600 feet deep. As the boundary cliffs were in great part vertical, it will readily be conceived that, amidst the various movements of the earth, the precipices overhanging rivers, being without support on one side, were often thrown down. We find, indeed, that inundations produced by obstructions in river-courses are among the most disastrous consequences of great earthquakes in all parts of the world, for the alluvial plains in the bottoms of valleys are usually the most fertile and well-peopled parts of the whole country; and whether the site of a town is above or below a temporary barrier in the channel of a river, it is exposed to injury by the waters either of a lake or flood.

Landslips. — From each side of the deep valley or ravine of Terranuova, enormous masses of the adjoining flat country were detached, and cast down into the course of the river, so as to give rise to great lakes. Oaks, olive-trees, vineyards, and corn, were often seen growing at the bottom of the ravine, as little injured

as their former companions, which still continued to flourish in the plain above, at least 500 feet higher, and at the distance of about three quarters of a mile. In one part of this ravine was an enormous mass, 200 feet high, and about 400 feet at its base, which had been detached by some former earthquake. It is well attested, that this mass travelled down the ravine nearly four miles, having been put in motion by the earthquake of the 5th of February. Hamilton, after examining the spot, declared that this phenomenon might be accounted for by the declivity of the valley, the great abundance of rain which fell, and the great weight of the alluvial matter which pressed behind it. Dolomieu also alludes to the fresh impulse derived from other masses falling, and pressing upon the rear of those first set in motion.

The first account sent to Naples of the two great slides or landslips above alluded to, which caused a great lake near Terranuova, was couched in these words:—"Two mountains on the opposite sides of a valley walked from their original position until they met in the middle of the plain, and there joining together, they intercepted the course of a river," &c. The expressions here used resemble singularly those applied to phenomena, probably very analogous, which are said to have occurred at Fez, during the great Lisbon earthquake, as also in Jamaica and Java at other periods.

Not far from Soriano, which was levelled to the ground by the great shock of February, a small valley, containing a beautiful olive-grove, called Fra Ramondo, underwent a most extraordinary revolution. Innumerable fissures first traversed the river-plain in all directions, and absorbed the water until the argilla-

ceous substratum became soaked, so that a great part of it was reduced to a state of fluid paste. Strange alterations in the outline of the ground were the consequence, as the soil to a great depth was easily moulded into any form. In addition to this change, the ruins of the neighbouring hills were precipitated into the hollow; and while many olives were uprooted, others remained growing on the fallen masses, and inclined at various angles (see Fig. 62). The small river Caridi was entirely concealed for many days; and when at length it reappeared, it had shaped for itself an entirely new channel.

Fig. 62.

Changes of the surface at Fra Ramondo, near Soriano, in Calabria.

1, Portion of a hill covered with olives thrown down.
2, New bed of the river Caridi. 3, Town of Soriano.

Buildings transported entire to great distances.— Near Seminara, an extensive olive-ground and orchard were hurled to a distance of two hundred feet, into a

valley sixty feet in depth. At the same time a deep chasm was riven in another part of the high platform from which the orchard had been detached, and the river immediately entered the fissure, leaving its former bed completely dry. A small inhabited house, standing on the mass of earth carried down into the valley, went along with it entire, and without injury to the inhabitants. The olive-trees, also, continued to grow on the land which had slid into the valley, and bore the same year an abundant crop of fruit.

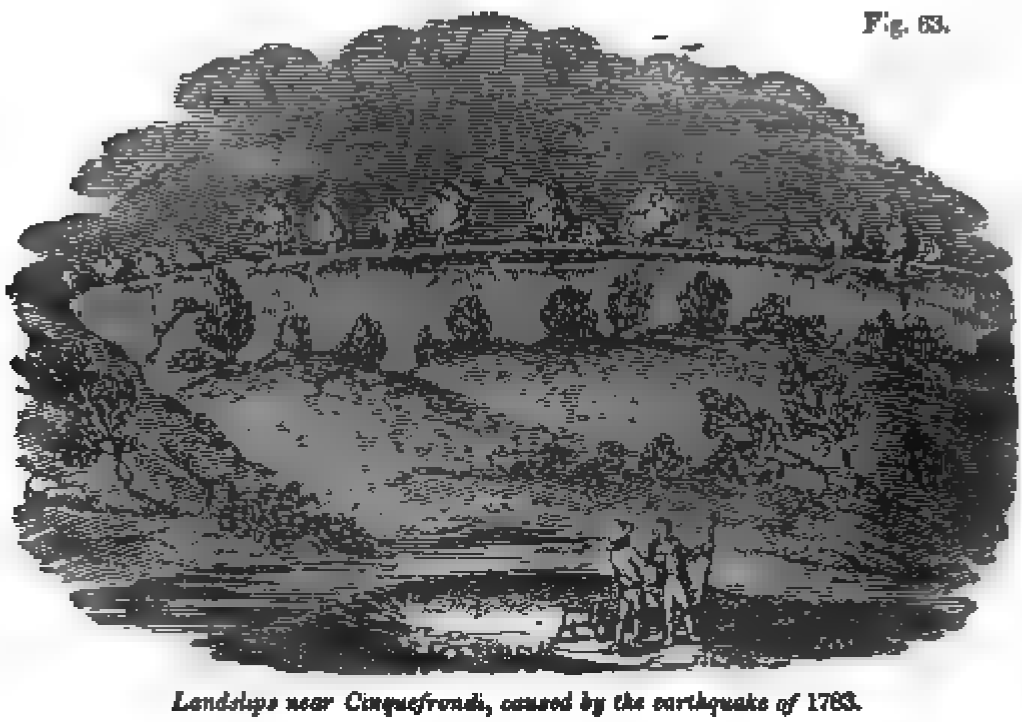
Two tracts of land on which a great part of the town of Polistena stood, consisting of some hundreds of houses, were detached into a contiguous ravine, and nearly across it, about half a mile from their original site; and what is most extraordinary, several of the inhabitants were dug out from the ruins alive and unhurt.

Two tenements, near Mileto, called the Macini and Vaticano, occupying an extent of ground about a mile long, and half a mile broad, were carried for a mile down a valley. A thatched cottage, together with large olive and mulberry trees, most of which remained erect, were carried uninjured to this extraordinary distance. According to Hamilton, the surface removed had been long undermined by rivulets, which were afterwards in full view on the bare spot deserted by the tenements. The earthquake seems to have opened a passage in the adjoining argillaceous hills, which admitted water charged with loose soil into the subterranean channels of the rivulets immediately under the tenements, so that the foundations of the ground set in motion by the earthquake were loosened. Another example of subsidence, where the edifices were not destroyed, is mentioned by Grimaldi, as having taken place in the city of Catanzaro, the capital of the pro-

vince of that name. The houses in the quarter called San Giuseppe subsided with the ground to various depths from two to four feet, but the buildings remained uninjured.

It would be tedious, and our space would not permit us, to follow the different authors through their local details of landslips produced in minor valleys; but they are highly interesting, as showing to how great an extent the power of rivers to widen valleys, and to carry away large portions of soil towards the sea, is increased where earthquakes are of periodical occurrence. Among other territories, that of Cinquefrondi

Fig. 63.



Landslips near Cinquefrondi, caused by the earthquake of 1783.

was greatly convulsed, various portions of soil being raised or sunk, and innumerable fissures traversing the country in all directions (see Fig. 63.). Along the flanks of a small valley in this district there appears to have been an almost uninterrupted line of landslips.

Number of new-formed lakes. — Vivenzio states, that near Sitizzano a valley was nearly filled up to a level with the high grounds on each side, by the enormous masses detached from the boundary hills, and cast down into the course of two streams. By this barrier a lake was formed of great depth, about two miles long and a mile broad. The same author mentions that, upon the whole, there were fifty lakes occasioned during the convulsions: and he assigns localities to all of these. The government surveyors enumerated 215 lakes, but they included in this number many small ponds.

Currents of mud. — Near S. Lucido, among other places, the soil is described as having been "dissolved," so that large torrents of mud inundated all the low grounds, like lava. Just emerging from this mud, the tops only of trees and of the ruins of farmhouses were seen. Two miles from Laureana, the swampy soil in two ravines became filled with calcareous matter, which oozed out from the ground immediately before the first great shock. This mud, rapidly accumulating, began, ere long, to roll onward, like a flood of lava, into the valley, where the two streams uniting, moved forward with increased impetus from east to west. It now presented a breadth of 225 feet by fifteen in depth, and, before it ceased to move, covered a surface equal in length to an Italian mile. In its progress it overwhelmed a flock of thirty goats, and tore up by the roots many olive and mulberry trees, which floated like ships upon its surface. When this calcareous lava had ceased to move, it gradually became dry and hard, during which process the mass was lowered seven feet and a half. It contained fragments of earth of a ferruginous colour, and emitting a sulphureous smell.

Cones of sand thrown up.— Many of the appearances exhibited in the alluvial plains indicate clearly the alternate rising and sinking of the ground. The first effect of the more violent shocks was usually to dry up the rivers, but they immediately afterwards overflowed their banks. Along the alluvial plains, and in marshy places, an immense number of cones of sand were thrown up. These appearances Hamilton explains, by supposing that the first movement raised the fissured plain from below upwards, so that the rivers and stagnant waters in bogs sank down, or at least were not upraised with the soil. But when the ground returned with violence to its former position, the water was thrown up in jets through fissures.*

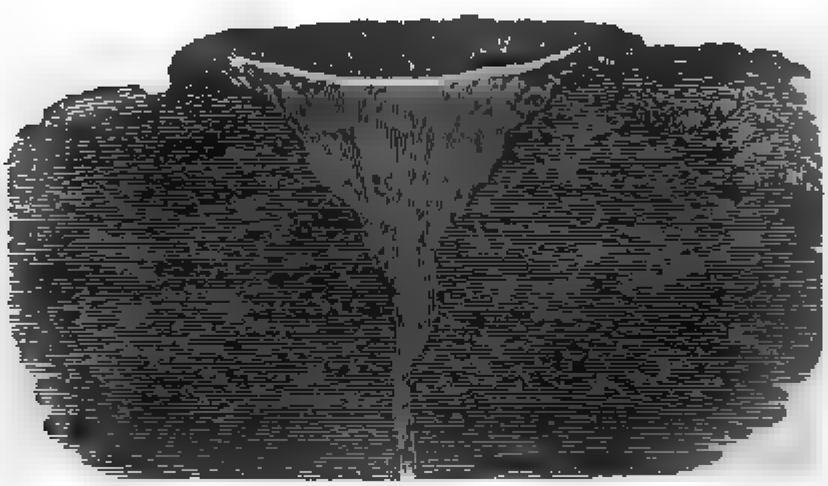
Fig. 64.

Circular hollows in the plain of Rosarno, formed by the earthquake of 1783.

* Phil. Trans. vol. lxxiii. p. 180.

Formation of circular hollows.— In the report of the Academy, we find that some plains were covered with circular hollows, for the most part about the size of carriage wheels, but often somewhat larger or smaller. When filled with water to within a foot or two of the surface, they appeared like wells; but, in general, they were filled with dry sand, sometimes with a concave surface, and at other times convex. (See Fig. 64.) On digging down, they found them to be funnel-shaped, and the moist loose sand in the centre marked the tube up which the water spouted. The annexed cut (Fig. 65.) represents a section of one of these inverted cones when the water had disappeared, and nothing but dry micaceous sand remained.

Fig. 65.



Section of one of the circular hollows formed in the plain of Rosarno.

Fall of the sea cliffs.— Along the sea-coast of the straits of Messina, near the celebrated rock of Scilla, the fall of huge masses detached from the bold and lofty cliffs overwhelmed many villas and gardens. At Gian Greco, a continuous line of cliff, for a mile in length, was thrown down. Great agitation was frequently observed in the bed of the sea during the

shocks, and, on those parts of the coast where the movement was most violent, all kinds of fish were taken in abundance, and with unusual facility. Some rare species, as that called Cicirelli, which usually lie buried in the sand, were taken on the surface of the waters in great quantity. The sea is said to have boiled up near Messina, and to have been agitated as if by a copious discharge of vapours from its bottom.

Shore near Scilla inundated.—The Prince of Scilla had persuaded a great part of his vassals to betake themselves to their fishing-boats for safety, and he himself had gone on board. On the night of the 5th of February, when some of the people were sleeping in the boats, and others on a level plain slightly elevated above the sea, the earth rocked, and suddenly a great mass was torn from the contiguous Mount Jaci, and thrown down with a dreadful crash upon the plain. Immediately afterwards, the sea, rising more than twenty feet above the level of this low tract, rolled foaming over it, and swept away the multitude. It then retreated, but soon rushed back again with greater violence, bringing with it some of the people and animals it had carried away. At the same time every boat was sunk or dashed against the beach, and some of them were swept far inland. The aged prince, with 1430 of his people, was destroyed.

State of Stromboli and Etna during the shocks.—The inhabitants of Pizzo remarked that, on the 5th of February, 1783, when the first great shock afflicted Calabria, the volcano of Stromboli, which is in full view of that town, and at the distance of about fifty miles, smoked less, and threw up a less quantity of inflamed matter, than it had done for some years previously. On the other hand, the great crater of Etna

is said to have given out a considerable quantity of vapour towards the beginning, and Stromboli towards the close, of the commotions. But as no eruption happened from either of these great vents during the whole earthquake, the sources of the Calabrian convulsions, and of the volcanic fires of Etna and Stromboli, appear to be very independent of each other; unless, indeed, they have the same mutual relation as Vesuvius and the volcanos of the Phlegræan Fields and Ischia, a violent disturbance in one district serving as a safety-valve to the other, and both never being in full activity at once.

Excavation of valleys.—It is impossible for the geologist to consider attentively the effect of this single earthquake of 1783, and to look forward to the alterations in the physical condition of the country to which a continued series of such movements will hereafter give rise, without perceiving that the formation of valleys by running water can never be understood, if we consider the question independently of the agency of earthquakes. It must not be imagined that rivers only begin to act when a country is already elevated far above the level of the sea, for their action must of necessity be most powerful while land is *rising* or *sinking* by successive movements. Whether Calabria is now undergoing any considerable change of relative level, in regard to the sea, or is, upon the whole, nearly stationary, is a question which our observations, confined almost entirely to the last half century, cannot possibly enable us to determine. But we know that strata, containing species of shells identical with those now living in the contiguous parts of the Mediterranean, have been raised in that country, as they have in Sicily, to the height of several thousand feet.

Now, those geologists who grant that the present course of Nature in the inanimate world has continued the same since the existing species of animals were in being, will not feel surprise that the Calabrian streams and rivers have cut out of such comparatively modern strata a great system of valleys, varying in depth from fifty to six hundred feet, and often several miles wide, if they consider how numerous must have been the earthquakes which lifted those recent marine strata to so prodigious a height. Some speculators, indeed, who disregard the analogy of existing Nature, and who are always ready to assume that her forces were more energetic in by-gone ages, may dispense with a long series of movements, and suppose that Calabria "rose like an exhalation" from the deep, after the manner of Milton's Pandemonium. But such an hypothesis would deprive them of that peculiar removing force required to form a regular system of deep and wide valleys; for *time*, which they are so unwilling to assume, is essential to the operation. Time must be allowed in the intervals between distinct convulsions, for running water to clear away the ruins caused by landslips, otherwise the fallen masses will serve as buttresses, and prevent the succeeding earthquake from exerting its full power. The sides of the valley must be again cut away by the stream, and made to form precipices and overhanging cliffs, before the next shock can take effect in the same manner.

Possibly the direction of the succeeding shock may not coincide with that of the valley, a great extent of adjacent country being equally shaken. Still it will usually happen that no permanent geographical change will be produced except in valleys. In them alone will occur landslips from the boundary cliffs, and these will

frequently divert the stream from its accustomed course, causing the original ravine to become both wider and more tortuous in its direction.

If a single convulsion of extreme violence should agitate at once an entire hydrographical basin, or if the shocks should follow each other too rapidly, the previously existing valleys would be annihilated, instead of being modified and enlarged. Every stream might in that case be compelled to begin its operations anew, and to shape out new channels, instead of continuing to deepen and widen those already excavated. But if the subterranean movements have been intermittent; and if sufficient periods have always intervened between the severer shocks to allow the drainage of the country to be nearly restored to its original state, then are both the kind and degree of force supplied by which running water may hollow out valleys of any depth or size consistent with the elevation above the sea which the districts drained by them may have attained.

When we read of the drying up and desertion of the channels of rivers, the accounts most frequently refer to their deflection into some other part of the same alluvial plain, perhaps several miles distant. Under certain circumstances, a change of level may undoubtedly force the water to flow over into some distinct hydrographical basin; but even then it will fall immediately into some other system of valleys already formed.

We learn from history that, ever since the first Greek colonists settled in Calabria, that region has been subject to devastation by earthquakes; and, for the last century and a half, ten years have seldom elapsed without a shock; but the severer convulsions have not only been separated by intervals of twenty,

fifty, or one hundred years; but have not affected precisely the same points when they recurred. Thus the earthquake of 1783, although confined within the same geographical limits as that of 1638, and not very inferior in violence, visited, according to Grimaldi, very different districts. The points where the local intensity of the force is developed being thus perpetually varied, more time is allowed, for the removal of separate mountain masses thrown into river channels by each shock.

Number of persons who perished during the earthquake.—The number of persons who perished during the earthquake in the two Calabrias and Sicily is estimated by Hamilton at about forty thousand, and about twenty thousand more died by epidemics, which were caused by insufficient nourishment, exposure to the atmosphere, and malaria, arising from the new stagnant lakes and pools.

By far the greater number were buried under the ruins of their houses; but many were burnt to death in the conflagrations which almost invariably followed the shocks. These fires raged the more violently in some cities, such as Oppido, from the immense magazines of oil which were consumed.

Many persons were engulphed in deep fissures, especially the peasants, when flying across the open country, and their skeletons may perhaps be buried in the earth to this day, at the depth of several hundred feet.

When Dolomieu visited Messina after the shock of Feb. 5th, he describes the city as still presenting, at least at a distance, an imperfect image of its ancient splendour. Every house was injured, but the walls were standing: the whole population had taken refuge

in wooden huts in the neighbourhood, and all was solitude and silence in the streets: it seemed as if the city had been desolated by the plague, and the impression made upon his feelings was that of melancholy and sadness. "But when I passed over to Calabria, and first beheld Polistena, the scene of horror almost deprived me of my faculties; my mind was filled with mingled compassion and terror; nothing had escaped; all was levelled with the dust; not a single house or piece of wall remained; on all sides were heaps of stone so destitute of form, that they gave no conception of there ever having been a town on the spot. The stench of the dead bodies still rose from the ruins. I conversed with many persons who had been buried for three, four, and even for five days: I questioned them respecting their sensations in so dreadful a situation, and they agreed that, of all the physical evils they endured, thirst was the most intolerable; and that their mental agony was increased by the idea that they were abandoned by their friends, who might have rendered them assistance." *

It is supposed that about a fourth part of the inhabitants of Polistena, and of some other towns, were buried alive, and might have been saved had there been no want of hands; but in so general a calamity, where each was occupied with his own misfortunes, or those of his family, aid could rarely be obtained. Neither tears, nor supplications, nor promises of high rewards were listened to. Many acts of self-devotion, prompted by parental and conjugal tenderness, or by friendship, or the gratitude of faithful servants, are recorded; but individual exertions were, for the most

* Dissertation on the Calabrian Earthquakes, &c. translated in Pinkerton's Voyages and Travels, vol. v.

part, ineffectual. It frequently happened, that persons in search of those most dear to them could hear their moans, — could recognize their voices, — were certain of the exact spot where they lay buried beneath their feet, yet could afford them no succour. The piled mass resisted all their strength, and rendered their efforts of no avail.

At Terranuova, four Augustin monks, who had taken refuge in a vaulted sacristy, the arch of which continued to support an immense pile of ruins, made their cries heard for the space of four days. One only of the brethren of the whole convent was saved, and "of what avail was his strength to remove the enormous weight of rubbish which had overwhelmed his companions?" He heard their voices die away gradually; and when afterwards their four corpses were disinterred, they were found clasped in each other's arms. Affecting narratives are preserved of mothers saved after the fifth, sixth, and even seventh day of their interment, when their infants or children had perished with hunger.

It might have been imagined that the sight of sufferings such as these would have been sufficient to awaken sentiments of humanity and pity in the most savage breasts, but while some acts of heroism are related, nothing could exceed the general atrocity of conduct displayed by the Calabrian peasants: they abandoned the farms, and flocked in great numbers into the towns — not to rescue their countrymen from a lingering death, but to plunder. They dashed through the streets, fearless of danger, amid tottering walls and clouds of dust, trampling beneath their feet the bodies of the wounded and half buried, and often stripping them, while yet living, of their clothes.*

* Dolomieu, ibid.

Concluding remarks. — But to enter more fully into these details would be foreign to the purpose of the present work, and several volumes would be required to give the reader a just idea of the sufferings which the inhabitants of many populous districts have undergone during the earthquakes of the last 150 years. A bare mention of the loss of life — as that fifty or a hundred thousand souls perished in one catastrophe — conveys to the reader no idea of the extent of misery inflicted: we must learn, from the narratives of eyewitnesses, the various forms in which death was encountered, the numbers who escaped with loss of limbs or serious bodily injuries, and the multitude who were suddenly reduced to penury and want. It has been often remarked, that the dread of earthquakes is strongest in the minds of those who have experienced them most frequently; whereas, in the case of almost every other danger, familiarity with peril renders men intrepid. The reason is obvious — scarcely any part of the mischief apprehended in this instance is imaginary; the first shock is often the most destructive; and, as it may occur in the dead of the night, or if by day, without giving the least warning of its approach, no forethought can guard against it; and when the convulsion has begun, no skill, or courage, or presence of mind, can point out the path of safety. During the intervals, of uncertain duration, between the more fatal shocks, slight tremors of the soil are not unfrequent; and as these sometimes precede more violent convulsions, they become a source of anxiety and alarm. The terror arising from this cause alone is of itself no inconsiderable evil.

Although sentiments of pure religion are frequently awakened by these awful visitations, yet we more

commonly find that an habitual state of fear, a sense of helplessness, and a belief in the futility of all human exertions, prepare the minds of the vulgar for the influence of a demoralizing superstition.

Where earthquakes are frequent, there can never be perfect security of property under the best government; industry cannot be assured of reaping the fruits of its labour; and the most daring acts of outrage may occasionally be perpetrated with impunity, when the arm of the law is paralysed by the general consternation. It is hardly necessary to add, that the progress of civilization and national wealth must be retarded by convulsions which level cities to the ground, destroy harbours, render roads impassable, and cause the most cultivated valley-plains to be covered with lakes, or the ruins of adjoining hills.

Those geologists who imagine that, at remote periods ere man became a sojourner on earth, the volcanic agency was more energetic than now, should be careful to found their opinion on strict geological evidence, and not permit themselves to be biassed, as they have often been, by a notion, that the disturbing force would probably be mitigated for the sake of man.

I shall endeavour to point out in the sequel, that the general tendency of subterranean movements, when their effects are considered for a sufficient lapse of ages, is eminently beneficial, and that they constitute an essential part of that mechanism by which the integrity of the habitable surface is preserved, and the very existence and perpetuation of dry land secured. Why the working of this same machinery should be attended with so much evil, is a mystery far beyond the reach of our philosophy, and must probably remain so until we are permitted to investigate, not our

planet alone and its inhabitants, but other parts of the moral and material universe with which they may be connected. Could our survey embrace other worlds, and the events, not of a few centuries only, but of periods as indefinite as those with which geology renders us familiar, some apparent contradictions might be reconciled, and some difficulties would doubtless be cleared up. But even then, as our capacities are finite, while the scheme of the universe may be infinite, both in time and space, it is presumptuous to suppose that all sources of doubt and perplexity would ever be removed. On the contrary, they might, perhaps, go on augmenting in number; for it has been justly said, that the greater the circle of light, the greater the boundary of darkness by which it is surrounded.*

* Sir H. Davy's Consolations in Travel, p. 246.

CHAPTER XVII.

EARTHQUAKES OF THE EIGHTEENTH CENTURY — *continued.*

Earthquake of Guatemala, 1773 — Java, 1772 — Truncation of a lofty cone — St. Domingo, 1770 — Colombia, 1766 — Lisbon, 1755 — Shocks felt throughout Europe, Northern Africa, and the West Indies — Great wave — Conception Bay, 1750 — Permanent elevation — Peru, 1746 — Kamtschatka, 1737 — Java, 1699 — Rivers obstructed by landslips — Subsidence in Sicily, 1693 — Moluccas, 1693 — Jamaica, 1692 — Large tracts engulphed — Portion of Port Royal sunk — Amount of change in the last 150 years — Elevation and subsidence of land in Bay of Baiæ — Evidence of the same afforded by the Temple of Serapis.

In the preceding chapters we have considered a small part of those earthquakes only which have occurred during the last sixty years, of which accurate and authentic descriptions happen to have been recorded. We may next proceed to examine some of earlier date, respecting which information of geological interest has been obtained.

Central America, June, 1773. — The town of Guatemala was founded, in 1742, on the side of a volcano, in a valley about three miles wide, opening to the South Sea; nine years afterwards it was destroyed by an earthquake, and again, in 1773, during an eruption of the volcano. The ground on which the town stood gaped open in deep fissures, until at length, after five days, the city, with all its riches, and eight thousand

families, is said to have been swallowed up in an abyss.* This account, however, must have been exaggerated, for the mouldering ruins of the old town are described by Mr. E. L. Page as existing in 1834. It was abandoned for many years, but has now been repeopled with 12,000 inhabitants; the new city, at the distance of about four leagues, having already acquired a population of about 40,000 persons.† This place also suffered by an earthquake in April, 1830.

Java, 1772. — *Truncation of a lofty cone.* — In the year 1772, Papandayang, formerly one of the loftiest volcanos in the island of Java, was in eruption. Before all the inhabitants on the declivities of the mountain could save themselves by flight, the ground began to give way, and a great part of the volcano fell in and disappeared. It is estimated that an extent of ground of the mountain itself and its immediate environs, fifteen miles long and full six broad, was by this commotion swallowed up in the bowels of the earth. Forty villages were destroyed, some being engulphed and some covered by the substances thrown out on this occasion, and 2957 of the inhabitants perished. A proportionate number of cattle were also killed, and most of the plantations of cotton, indigo, and coffee in the adjacent districts were buried under the volcanic matter. This catastrophe appears to have resembled, although on a grander scale, that of the ancient Vesuvius in the year 79. The cone was reduced in height from nine thousand to about five thousand feet; and, as vapours still escape from the crater on its summit, a new cone may one day rise out of the ruins of the

* Dodsley's Ann. Regist. vol. xvi. p. 149.

† Geographical Journal, vol. viii. p. 321.

ancient mountain, as the modern Vesuvius has risen from the remains of Somma.*

Caucasus, 1772. — About the year 1772, an earthquake convulsed the ground in the province at Beshtau, in the Caucasus, so that part of the hill Metshuka sunk into an abyss.†

St. Domingo, 1770. — During a tremendous earthquake which destroyed a great part of St. Domingo, innumerable fissures were caused throughout the island, from which mephitic vapours emanated and produced an epidemic. *Hot springs* burst forth in many places where there had been no water before; but after a time they ceased to flow.‡

Colombia, 1766. — On the 21st of October, 1766, the ground was agitated at once at Cumana, at Caraccas, at Maraycabo, and on the banks of the rivers Casanare, the Meta, the Orinoco, and the Ventuario, These districts were much fissured, and great fallings in of the earth took place in the mountain Paurari: Trinidad was violently shaken. A small island in the Orinoco, near the rock Aravacoto, sunk down and disappeared.§ At the same time the ground was raised in the sea near Cariaco, where the point Del Gardo was enlarged. A rock also rose up in the river Gua-

* Dr. Horsfield, Batav. Trans. vol. viii. p. 26. Dr. H. informs me that he has seen this truncated mountain: and, though he did not ascend it, he has conversed with those who have examined it. Raffles's account (History of Java, vol. i.) is derived from Horsfield.

† Pallas's Travels in Southern Russia.

‡ Essai sur l'Hist. Nat. de l'Isle de St. Domingue. Paris, 1776.

§ Humboldt's Personal Narrative, vol. iv. p. 45.; and Saggio di Storia Americana, vol. ii. p. 6.

rapica, near the village of Maturin.* The shocks continued in Colombia hourly for fourteen months.

Hindostan, 1762. — The town of Chittagong, in Bengal, was violently shaken by an earthquake, on the 2d of April, 1762, the earth opening in many places, and throwing up water and mud of a sulphureous smell. At a place called Bardavan a large river was dried up; and at Bar Charra, near the sea, a tract of ground sunk down, and 200 people, with all their cattle, were lost. It is said, that sixty square miles of the Chittagong coast suddenly and permanently subsided during this earthquake, and that Ces-lung-Toom, one of the Mug mountains, entirely disappeared, and another sank so low, that its summit only remained visible. Four hills are also described as having been variously rent asunder, leaving open chasms from thirty to sixty feet in width. Towns which subsided several cubits were overflowed with water; among others, Deep Gong, which was submerged to the depth of seven cubits. Two volcanos are said to have opened in the Secta Cunda hills. The shock was also felt at Calcutta.†

Lisbon, 1755. — In no part of the volcanic region of southern Europe has so tremendous an earthquake occurred in modern times as that which began on the 1st of November, 1755, at Lisbon. A sound of thunder was heard underground, and immediately afterwards a violent shock threw down the greater part of that city. In the course of about six minutes, sixty thousand persons perished. The sea first retired

* Humboldt, Voy. Relat. Hist., part i. p. 307.; and part ii. p. 23.

† M'Clelland's Report on Min. Resources of India, 1838. Calcutta. For other particulars, see Phil. Trans. vol. liii.

and laid the bar dry; it then rolled in, rising fifty feet or more above its ordinary level. The mountains of Arrabida, Estrella, Julio, Marvan, and Cintra, being some of the largest in Portugal, were impetuously shaken, as it were, from their very foundations; and some of them opened at their summits, which were split and rent in a wonderful manner, huge masses of them being thrown down into the subjacent valleys.* Flames are related to have issued from these mountains, which are supposed to have been electric; they are also said to have smoked; but vast clouds of dust may have given rise to this appearance.

Subsidence of the quay.—The most extraordinary circumstance which occurred at Lisbon during the catastrophe was the subsidence of a new quay, built entirely of marble at an immense expense. A great concourse of people had collected there for safety, as a spot where they might be beyond the reach of falling ruins; but, suddenly, the quay sank down with all the people on it, and not one of the dead bodies ever floated to the surface. A great number of boats and small vessels anchored near it, all full of people, were swallowed up, as in a whirlpool.† No fragments of these wrecks ever rose again to the surface, and the water in the place where the quay had stood is stated, in many accounts, to be unfathomable; but Whitehurst says, he ascertained it to be one hundred fathoms.‡

In this case, we must either suppose that a certain tract sank down into a subterranean hollow, which

* Hist. and Philos. of Earthquakes, p. 317.

† Rev. C. Davy's Letters, vol. ii. Letter ii. p. 12., who was at Lisbon at the time, and ascertained that the boats and vessels said to have been swallowed were missing.

‡ On the Formation of the Earth, p. 55.

would cause a "fault" in the strata to the depth of six hundred feet, or we may infer, as some have done, from the entire disappearance of the substances engulphed, that a chasm opened and closed again. Yet, in adopting this latter hypothesis, we must suppose that the upper part of the chasm, to the depth of one hundred fathoms remained open after the shock. According to the observations made at Lisbon, in 1837, by Mr. Sharpe, the destroying effects of this earthquake were confined to the tertiary strata, and were most violent on the blue clay, on which the lower part of the city is constructed. Not a building, he says, on the secondary limestone or the basalt was injured.*

Area over which the earthquake extended.—The great area over which this Lisbon earthquake extended is very remarkable. The movement was most violent in Spain, Portugal, and the north of Africa; but nearly the whole of Europe, and even the West Indies, felt the shock on the same day. A seaport, called St. Ubes, about twenty miles south of Lisbon, was engulphed. At Algiers and Fez, in Africa, the agitation of the earth was equally violent; and at the distance of eight leagues from Morocco, a village with the inhabitants, to the number of about eight or ten thousand persons, together with all their cattle, were swallowed up. Soon after the earth closed again over them.

Shocks felt at sea.—The shock was felt at sea, on the deck of a ship to the west of Lisbon, and produced very much the same sensation as on dry land. Off St. Lucar, the captain of the ship Nancy felt his vessel so violently shaken, that he thought she had struck the ground; but, on heaving the lead, found a great depth

* Geol. Soc. Proceedings, No. 60. p. 36. 1838.

of water. Captain Clark, from Denia, in latitude 36° 24′ N., between nine and ten in the morning, had his ship shaken and strained as if she had struck upon a rock, so that the seams of the deck opened, and the compass was overturned in the binnacle. Another ship, forty leagues west of St. Vincent, experienced so violent a concussion, that the men were thrown a foot and a half perpendicularly up from the deck. In Antigua and Barbadoes, as also in Norway, Sweden, Germany, Holland, Corsica, Switzerland, and Italy, tremors and slight oscillations of the ground were felt.

Rate at which the movement travelled.—The agitation of lakes, rivers, and springs, in Great Britain, was remarkable. At Loch Lomond, in Scotland, for example, the water, without the least apparent cause, rose against its banks, and then subsided below its usual level. The greatest perpendicular height of this swell was two feet four inches. It is said that the movement of this earthquake was undulatory, and that it travelled at the rate of twenty miles a minute, its velocity being calculated by the intervals between the time when the first shock was felt at Lisbon and its time of occurrence at other distant places.*

Great wave and retreat of the sea.—A great wave swept over the coast of Spain, and is said to have been sixty feet high at Cadiz. At Tangier, in Africa, it rose and fell eighteen times on the coast. At Funchal, in Madeira, it rose full fifteen feet perpendicular above high-water mark, although the tide, which ebbs and flows there seven feet, was then at half ebb. Besides entering the city, and committing great havoc,

* Michell on the Cause and Phenomena of Earthquakes, Phil. Trans. vol. li. p. 566. 1760.

it overflowed other seaports in the island. At Kinsale, in Ireland, a body of water rushed into the harbour, whirled round several vessels, and poured into the market-place.

It was before stated that the sea first retired at Lisbon; and this retreat of the ocean from the shore, at the commencement of an earthquake and its subsequent return in a violent wave, is a common occurrence. In order to account for the phenomenon, Michell imagined a subsidence at the bottom of the sea, from the giving way of the roof of some cavity in consequence of a vacuum produced by the condensation of steam. Such condensation, he observes, might be the first effect of the introduction of a large body of water into fissures and cavities already filled with steam, before there has been sufficient time for the heat of the incandescent lava to turn so large a supply of water into steam, which being soon accomplished causes a greater explosion.

Another proposed explanation is, the sudden rise of the land, which would cause the sea to abandon immediately the ancient line of coast; and if the shore, after being thus heaved up, should fall again to its original level, the ocean would return. This theory, however, will not account for the facts observed during the Lisbon earthquake; for the retreat preceded the wave, not only on the coast of Portugal, but also at the island of Madeira, and several other places. If the upheaving of the coast of Portugal had caused the retreat, the motion of the waters, when propagated to Madeira, would have produced a wave previous to the retreat. Nor could the motion of the waters at Madeira have been caused by a different local earthquake; for the shock travelled from Lisbon to Madeira in two

hours, which agrees with the time which it required to reach other places equally distant.*

The following is another solution of the problem, which has been offered :—Suppose a portion of the bed of the sea to be suddenly upheaved, the first effect will be to raise over the elevated part a body of water, the momentum of which will carry it much above the level it will afterwards assume, causing a draught or receding of the water from the neighbouring coasts, followed immediately by the return of the displaced water, which will also be impelled by its momentum much farther and higher on the coast than its former level.†

Mr. Darwin, when alluding to similar waves on the coast of Chili, states his opinion, that "the whole phenomenon is due to a common undulation in the water, proceeding from a line or point of disturbance some little way distant. If the waves," he says, "sent off from the paddles of a steam vessel be watched breaking on the sloping shore of a still river, the water will be seen first to retire two or three feet, and then to return in little breakers, precisely analogous to those consequent on an earthquake." He also adds, that "the earthquake wave occurs some time after the shock, the water at first retiring both from the shores of the mainland and of outlying islands, and then returning in mountainous breakers. Their size is modified by the form of the neighbouring coast; for it is ascertained in South America, that places situated at the head of shoaling bays have suffered most, whereas towns like Valparaiso, seated close on the border of a

* Michell, Phil. Trans. vol. li. p. 614.

† Quarterly Review, No. lxxxvi. p. 459.

profound ocean, have never been inundated, though severely shaken by earthquakes."*

St. Domingo, 1751.— On the 15th of September, 1751, an earthquake began in several of the West India Islands; and on the 21st of November, a violent shock destroyed the capital of St. Domingo, Port au Prince. Part of the coast, twenty leagues in length, sank down, and has ever since formed a bay of the sea.†

Chili, 1751.—On the 24th of May, 1751, the ancient town of Conception, otherwise called Penco, was totally destroyed by an earthquake, and the sea rolled over it. (See plan of the bay, Fig. 52. p. 298.) The ancient port was rendered entirely useless, and the inhabitants built another town about ten miles from the sea-coast, in order to be beyond the reach of similar inundations. At the same time, a colony recently settled on the sea-shore of Juan Fernandez was almost entirely overwhelmed by a wave which broke upon the shore.

It has been already stated, that in 1835, or eighty-four years after the destruction of Penco, the same coast was overwhelmed by a similar flood from the sea during an earthquake; and it is also known, that twenty-one years before (or in 1730), a like wave rolled over these fated shores, in which many of the inhabitants perished. A series of similar catastrophes has also been traced back as far as the year 1590‡, beyond which we have no memorials save those of oral

* Darwin's Travels in South America, &c. 1832 to 1836. Voyage of H. M. S. Beagle, vol. iii. p. 377.

† Hist. de l'Acad. des Sciences. 1752. Paris.

‡ See Father Acosta's work; and Sir Woodbine Parish, Geol. Soc. Proceedings, vol. ii. p. 215.

tradition. Molina, who has recorded the customs and legends of the aborigines, tells us, that the Araucanian Indians, a tribe inhabiting the country between the Andes and Pacific, including the part now called Chili, "had among them a tradition of a great deluge, in which only a few persons were saved, who took refuge upon a high mountain called Thegtheg, 'the thundering,' which had three points. Whenever a violent earthquake occurs, these people fly for safety to the mountains, assigning as a reason, that they are fearful, after the shock, that the sea will again return and deluge the world."*

Notwithstanding the tendency of writers in his day to refer all traditionary inundations to one remote period, Molina remarks that this flood of the Araucanians "was probably very different from that of Noah." We have, indeed, no means of conjecturing how long this same tribe had flourished in Chili, but we can scarcely doubt, that if its experience reached back even for three or four centuries, several inroads of the ocean must have occurred within that period. But the memory of a succession of physical events, similar in kind, though distinct in time, can never be preserved by a people destitute of written annals. Before two or three generations have passed away all dates are forgotten, and even the events themselves, unless they have given origin to some customs, or religious rites and ceremonies. Oftentimes the incidents of many different earthquakes and floods become blended together in the same narrative; and in such cases the single catastrophe is described in terms

* Molina, Hist. of Chili, vol. ii. p. 93.

so exaggerated, or is so disguised by mythological fictions, as to be utterly valueless to the antiquary or philosopher.

Proofs of elevation of twenty-four feet.—During a late survey of Conception Bay, Captains Beechey and Belcher discovered that the ancient harbour, which formerly admitted all large merchant vessels which went round the Cape, is now occupied by a reef of sandstone, certain points of which project above the sea at low water, the greater part being very shallow. A tract of a mile and a half in length, where, according to the report of the inhabitants, the water was formerly four or five fathoms deep, is now a shoal; consisting, as our hydrographers found, of hard sandstone, so that it cannot be supposed to have been formed by recent deposits of the river Biobio, an arm of which carries down loose micaceous sand into the same bay.

It is impossible at this distance of time to affirm that the bed of the sea was uplifted at once to the height of twenty-four feet, during the single earthquake of 1751, because other movements may have occurred subsequently; but it is said, that ever since the shock of 1751, no vessels have been able to approach within a mile and a half of the ancient port of Penco. (See Map, p. 298.) In proof of the former elevation of the coast near Penco our surveyors found above high-water mark an enormous bed of shells of the same species as those now living in the bay, filled with micaceous sand like that which the Biobio now conveys to the bay. These shells, as well as others, which cover the adjoining hills of mica-schist to the height of several hundred feet, have lately been examined by experienced conchologists in London, and identified

with those taken at the same time in a living state from the bay and its neighbourhood.*

Ulloa, therefore, was perfectly correct in his statement that, at various heights above the sea between Talcahuano and Conception, "mines were found of various sorts of shells used for lime of the very same kinds as those found in the adjoining sea." Among them he mentions the great mussel called Choros, and two others which he describes. Some of these, he says, are entire, and others broken; they occur at the bottom of the sea, in four, six, ten, or twelve fathom water, where they adhere to a sea-plant called Cochayuyo. They are taken in dredges, and have no resemblance to those found on the shore or in shallow water; yet beds of them occur at various heights on the hills. "I was the more pleased with the sight," he adds, "as it appeared to me a convincing proof of the universality of the deluge, although I am not ignorant that some have attributed their position to other causes." † It has, however, been asserted that the foundation of the Castle of Penco was so low in 1835, or at so inconsiderable an elevation above the highest spring tides, as to discountenance the idea of any permanent upheaval in modern times, on the site of that ancient port; but no exact measurements or levellings appear as yet to have been made to determine this point, which is the more worthy of investigation, because it may throw some light on an opinion often promulgated of late years, that there is a tendency in the Chilian coast, after each upheaval, to sink gradually and return towards its former position.

* Captain Belcher has shown me these shells, and the collection has been examined by Mr. Broderip.

† Ulloa's Voyage to South America, vol. ii. book viii. ch. vi.

Peru, 1746.—Peru was visited, on the 28th of October, 1746, by a tremendous earthquake. In the first twenty-four hours, two hundred shocks were experienced. The ocean twice retired and returned impetuously upon the land: Lima was destroyed, and part of the coast near Callao was converted into a bay: four other harbours, among which were Cavalla and Guanape, shared the same fate. There were twenty-three ships and vessels, great and small, in the harbour of Callao, of which nineteen were sunk; and the other four, among which was a frigate called St. Fermin, were carried by the force of the waves to a great distance up the country, and left on dry ground at considerable heights above the sea. The number of inhabitants in this city amounted to four thousand. Two hundred only escaped, twenty-two of whom were saved on a small fragment of the fort of Vera Cruz, which remained as the only memorial of the town after this dreadful inundation. Other portions of its site were completely covered with heaps of sand and gravel.

A volcano in Lucanas burst forth the same night, and such quantities of water descended from the cone that the whole country was overflowed; and in the mountain near Pataz, called Conversiones de Caxamarquilla, three other volcanos burst out, and frightful torrents of water swept down their sides.*

There are several records of prior convulsions in Peru, accompanied by similar inroads of the sea, one of which happened fifty-nine years before (in 1687), when the ocean, according to Ulloa, first retired and then returned in a mountainous wave, overwhelming Callao and its environs with the miserable inhabitants.†

* Ulloa's Voyage, vol. ii. book vii. chap. vii.

† Ibid. vol. ii. p. 82.

This same wave, according to Lionel Wafer, carried ships a league into the country, and drowned man and beast for fifty leagues along the shore.* Inundations of still earlier dates are carefully recorded by Ulloa, Wafer, Acosta, and various writers, who describe them as having expended their chief fury some on one part of the coast some on another.

But all authentic accounts cease when we ascend to the era of the conquest of Peru by the Spaniards. The ancient Peruvians, although far removed from barbarism, were without written annals, and therefore unable to preserve a distinct recollection of a long series of natural events. They had, however, according to Antonio de Herrera, who, in the beginning of the seventeenth century investigated their antiquities, a tradition, " that many years before the reign of the Incas, at a time when the country was very populous, there happened a great flood; the sea breaking out beyond its bounds, so that the land was covered with water, and all the people perished. To this the Guacas, inhabiting the vale of Xausca, and the natives of Chiquito, in the province of Callao, add that some persons remained in the hollows and caves of the highest mountains, who again peopled the land. Others of the mountain people affirm that all perished in the deluge, only six persons being saved on a float, from whom descended all the inhabitants of that country." †

On the mainland near Lima, and on the neighbouring island of San Lorenzo, Mr. Darwin found proofs that the ancient bed of the sea had been raised to the

* Wafer, cited by Sir W. Parish, Geol. Soc. Proceedings, v. ii. p. 215.

† Hist. of America, decad. iii. book xi. chap. i.

height of more than eighty feet above water within the human epoch, strata having been discovered at that altitude, containing pieces of cotton-thread and plaited rush, together with sea-weed and marine shells.* The same author learnt from Mr. Gill, a civil engineer, that he discovered in the interior, near Lima, between Casma and Huaraz, the dried-up channel of a large river, sometimes worn through solid rock, which, instead of continually ascending towards its source, has, in one place, a steep downward slope in that direction, for a ridge or line of hills has been uplifted directly across the bed of the stream, which is now arched. By these changes the water has been turned into some other course; and a district, once fertile, and still covered with ruins, and bearing the marks of ancient cultivation, has been converted into a desert.†

Kamtschatka, 1737, &c. — There are records of earthquakes in Kamtschatka and the Kurile Isles, in 1737, — in Martinique, in 1727, — Iceland, 1725, — Teneriffe, 1706, — during which the shape of the ground both above and beneath the level of the sea was greatly changed.

Java, 1699. — On the 5th of January, 1699, a terrible earthquake visited Java, and no less than 208 considerable shocks were reckoned. Many houses in Batavia were overturned, and the flame and noise of a volcanic eruption were seen and heard in that city, which were afterwards found to proceed from Mount Salak, ‡ a volcano six days' journey distant. Next morning the Batavian river, which has its rise from that mountain, became very high and muddy, and brought down abundance of bushes and trees, half

* Darwin's Journal, p. 451.   † Ibid. p. 413.

‡ Misspelt Sales in Hooke's Account.

burnt. The channel of the river being stopped up, the water overflowed the country round the gardens about the town, and some of the streets, so that fishes lay dead in them. All the fish in the river, except the carps, were killed by the mud and turbid water. A great number of drowned buffaloes, tigers, rhinoceroses, deer, apes, and other wild beasts, were brought down by the current; and, "notwithstanding," observes one of the writers, "that a crocodile is amphibious, several of them were found dead among the rest." *

It is stated, that seven hills bounding the river sank down; by which is merely meant, as by similar expressions in the description of the Calabrian earthquakes, seven great landslips. These hills, descending some from one side of the valley and some from the other, filled the channel, and the waters then finding their way under the mass, flowed out thick and muddy. The Tangaran river was also dammed up by nine hills, and in its channel were large quantities of drift trees. Seven of its tributaries also are said to have been "covered up with earth." A high tract of forest land, between the two great rivers before mentioned, is described as having been changed into an open country, destitute of trees, the surface being spread over with a fine red clay. This part of the account may, perhaps, merely refer to the sliding down of woody tracts into the valleys, as happened to so many extensive vineyards and olive grounds in Calabria, in 1783. The close packing of large trees in the Batavian river is represented as very remarkable, and it attests in a striking manner the destruction of soil bordering the

* Hooke's Posthumous Works, p. 437. 1705.

valleys which had been caused by floods and landslips.*

Quito, 1698.—In Quito, on the 19th of July, 1698, during an earthquake, a great part of the crater and summit of the volcano Carguairazo fell in, and a stream of water and mud issued from the broken sides of the hill.†

Sicily, 2693.—Shocks of earthquakes spread over all Sicily in 1693, and on the 11th of January the city of Catania and forty-nine other places were levelled to the ground, and about one hundred thousand people killed. The bottom of the sea, says Vicentino Bonajutus, sank down considerably, both in ports, inclosed bays, and open parts of the coast, and water bubbled up along the shores. Numerous long fissures of various breadths were caused, which threw out sulphureous water; and one of them, in the plain of Catania (the delta of the Simeto), at the distance of four miles from the sea, sent forth water as salt as the sea. The stone buildings of a street in the city of Noto, for the length of half a mile, sank into the ground, and remained hanging on one side. In another street, an opening large enough to swallow a man and horse appeared.‡

Moluccas, 1693.—The small isle of Sorea, which consists of one great volcano, was in eruption in the year 1693. Different parts of the cone fell, one after the other, into a deep crater, until almost half the space of the island was converted into a fiery lake. Most of the inhabitants fled to Banda; but great pieces of the mountain continued to fall down, so that the lake of lava became wider; and finally the whole population was compelled to emigrate. It is stated that

* Phil. Trans. 1700. † Humboldt, Atl. Pit. p. 106.

‡ Phil. Trans. 1693–4.

in proportion as the burning lake increased in size, the earthquakes were less vehement.*

Jamaica, 1692.—In the year 1692, the island of Jamaica was visited by a violent earthquake; the ground swelled and heaved like a rolling sea, and was traversed by numerous cracks, two or three hundred of which were often seen at a time, opening and then closing rapidly again. Many people were swallowed up in these rents; some the earth caught by the middle, and squeezed to death; the heads of others only appeared above ground; and some were first engulphed, and then cast up again with great quantities of water. Such was the devastation, that even at Port Royal, then the capital, where more houses are said to have been left standing than in the whole island beside, three quarters of the buildings, together with the ground they stood on, sank down with their inhabitants entirely under water.

Subsidence in the harbour.—The large store-houses on the harbour side subsided, so as to be twenty-four, thirty-six, and forty-eight feet under water; yet many of them appear to have remained standing, for it is stated that, after the earthquake, the mast-heads of several ships wrecked in the harbour, together with the chimney-tops of houses, were just seen projecting above the waves. A tract of land round the town, about a thousand acres in extent, sank down in less than one minute, during the first shock, and the sea immediately rolled in. The Swan frigate, which was repairing in the wharf, was driven over the tops of many buildings, and then thrown upon one of the roofs, through which it broke. The breadth of one of the streets is said to have been doubled by the earthquake,

* Phil. Trans. 1698.

According to Mr. De la Beche, the part of Port Royal described as having sunk was built upon newly formed land, consisting of sand, in which spiles had been driven; and the *settlement* of this loose sand, charged with the weight of heavy houses, may, he suggests, have given rise to the subsidences alluded to.*

There have undoubtedly been instances in Calabria and elsewhere of slides of land on which the houses have still remained standing; and it is possible that such may have been the case at Port Royal. The fact at least of submergence is unquestionable, for I have been informed by Admiral Sir Charles Hamilton that he frequently saw the submerged houses of Port Royal in the year 1780, in that part of the harbour which lies between the town and the usual anchorage of men-of-war. Bryan Edwards also says, in his History of the West Indies, that in 1793 the *ruins* were visible in clear weather from the boats which sailed over them.† Lastly, Lieutenant B. Jeffery, R. N., tells me that, being engaged in a survey between the years 1824 and 1835, he repeatedly visited the site in question, where the depth of the water is from four to six fathoms, and, whenever there was but little wind, perceived distinct traces of houses. He saw these more clearly when he used the instrument called the "diver's eye," which is let down below the ripple of the wave.‡

At several thousand places in Jamaica the earth is related to have opened. On the north of the island, several plantations, with their inhabitants, were swallowed up, and a lake appeared in their place, covering above a thousand acres, which afterwards dried up,

* Manual of Geol. p. 133. second edition.

† Vol. i. p. 235. 8vo. ed. 3 vols. 1801.

‡ Letter to the Author, May, 1838.

leaving nothing but sand and gravel, without the least sign that there had ever been a house or a tree there. Several tenements at Yallows were buried under land-slips; and one plantation was removed half a mile from its place, the crops continuing to grow upon it uninjured. Between Spanish Town and Sixteen-mile Walk, the high and perpendicular cliffs bounding the river fell in, stopped the passage of the river, and flooded the latter place for nine days, so that the people "concluded it had been sunk as Port Royal was." But the flood at length subsided, for the river had found some new passage at a great distance.

Mountains shattered.—The Blue and other of the highest mountains are declared to have been strangely torn and rent. They appeared shattered and half-naked, no longer affording a fine green prospect, as before, but stripped of their woods and natural verdure. The rivers on these mountains first ceased to flow for about twenty-four hours, and then brought down into the sea, at Port Royal and other places, several hundred thousand tons of timber, which looked like floating islands on the ocean. The trees were in general barked, most of their branches having been torn off in the descent. It is particularly remarked in this, as in the narratives of so many earthquakes, that fish were taken in great numbers on the coast during the shocks. The correspondents of Sir Hans Sloane, who collected with care the accounts of eye-witnesses of the catastrophe, refer constantly to *subsidences*, and some supposed the whole of Jamaica to have sunk down.*

Reflections on the amount of change in the last one hundred and forty years.—I have now only enumerated the earthquakes of the last 150 years, respecting

* Phil. Trans. 1694.

which facts illustrative of geological inquiries are on record. Even if my limits permitted, it would be a tedious and unprofitable task to examine all the obscure and ambiguous narratives of similar events of earlier epochs; although, if the places were now examined by geologists well practised in the art of interpreting the monuments of physical changes, many events which have happened within the historical era might still be determined with precision. It must not be imagined that, in the above sketch of the occurrences of a short period, I have given an account of all, or even the greater part, of the mutations which the earth has undergone by the agency of subterranean movements. Thus, for example, the earthquake of Aleppo, in the present century, and of Syria, in the middle of the eighteenth, would doubtless have afforded numerous phenomena, of great geological importance, had those catastrophes been described by scientific observers. The shocks in Syria, in 1759, were protracted for three months, throughout a space of ten thousand square leagues; an area compared to which that of the Calabrian earthquake in 1783 was insignificant. Accon, Saphat, Balbeck, Damascus, Sidon, Tripoli, and many other places, were almost entirely levelled to the ground. Many thousands of the inhabitants perished in each; and, in the valley of Balbeck alone, twenty thousand men are said to have been victims to the convulsion. In the absence of scientific accounts, it would be as irrelevant to our present purpose to enter into a detailed account of such calamities, as to follow the track of an invading army, to enumerate the cities burnt or rased to the ground, and reckon the number of individuals who perished by famine or the sword.

Deficiency of historical records. — If such, then, be the amount of ascertained changes in the last 150 years, notwithstanding the extreme deficiency of our records during that brief period, how important must we presume the physical revolutions to have been in the course of thirty or forty centuries, during which some countries habitually convulsed by earthquakes have been peopled by civilized nations! Towns engulphed during one earthquake may, by repeated shocks, have sunk to great depths beneath the surface, while the ruins remain as imperishable as the hardest rocks in which they are enclosed. Buildings and cities, submerged, for a time, beneath seas or lakes, and covered with sedimentary deposits, must, in some places, have been re-elevated to considerable heights above the level of the ocean. The signs of these events have, probably, been rendered visible by subsequent mutations, as by the encroachments of the sea upon the coast, by deep excavations made by torrents and rivers, by the opening of new ravines, and chasms, and other effects of natural agents, so active in districts agitated by subterranean movements.

If it be asked why, if such wonderful monuments exist, so few have hitherto been brought to light, we reply — because they have not been searched for. In order to rescue from oblivion the memorials of former occurrences, the inquirer must know what he may reasonably expect to discover; and under what peculiar local circumstances. He must be acquainted with the action and effect of physical causes, in order to recognize, explain, and describe correctly the phenomena when they present themselves.

The best known of the great volcanic regions, of which the boundaries were sketched in the tenth chap-

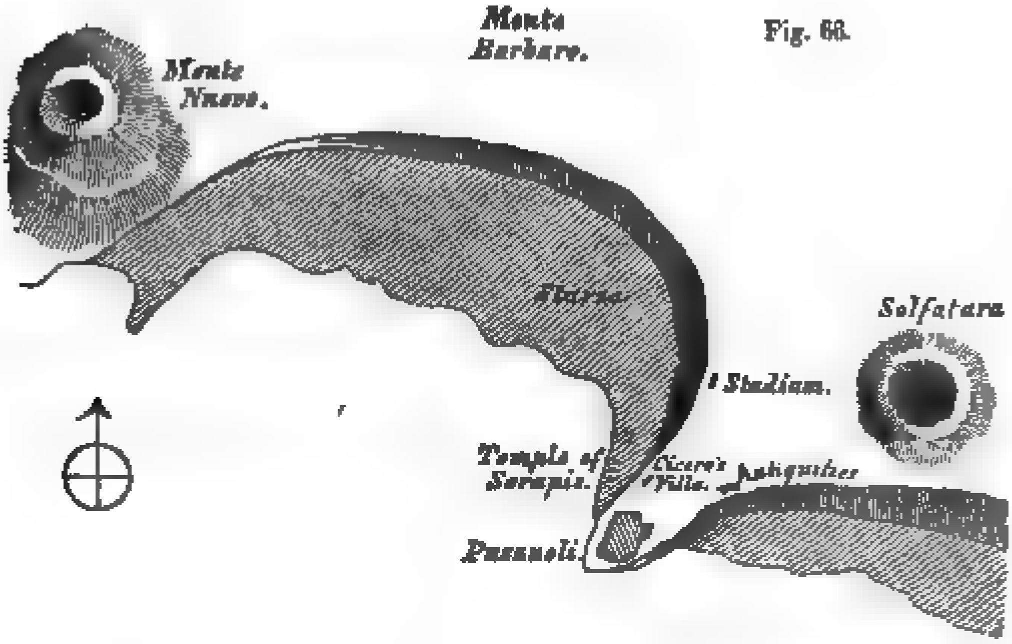
ter, is that which includes Southern Europe, Northern Africa and Central Asia; yet nearly the whole, even of this region, must be laid down, in a geological map, as "Terra Incognita." Even Calabria may be regarded as unexplored, as also Spain, Portugal, the Barbary States, the Ionian Isles, Asia Minor, Cyprus, Syria, and the countries between the Caspian and Black seas. We are, in truth, beginning to obtain some insight into one small spot of that great zone of volcanic disturbance, the district around Naples; a tract by no means remarkable for the violence of the earthquakes which have convulsed it.

If, in this part of Campania, we are enabled to establish, that considerable changes in the relative level of land and sea have taken place since the Christian era, it is all that we could have expected; and it is to recent antiquarian and geological research, not to history, that we are principally indebted for the information. I shall now proceed to lay before the reader some of the results of modern investigations in the Bay of Baiæ and the adjoining coast.

PROOFS OF ELEVATION AND SUBSIDENCE IN THE BAY OF BAIÆ.

Temple of Jupiter Serapis.—This celebrated monument of antiquity affords, in itself alone, unequivocal evidence that the relative level of land and sea has changed twice at Puzzuoli since the Christian era; and each movement, both of elevation and subsidence, has exceeded twenty feet. Before examining these proofs, I may observe, that a geological examination of the coast of the Bay of Baiæ, both on the north and south of Puzzuoli, establishes, in the most satis-

Fig. 68.



Ground plan of the coast of the Bay of Baiæ, in the environs of Puzzuoli.

factory manner, an elevation, at no remote period, of more than twenty feet, and, at one point, of more than thirty feet; and the evidence of this change would have been complete, even if the temple had, to this day, remained undiscovered.

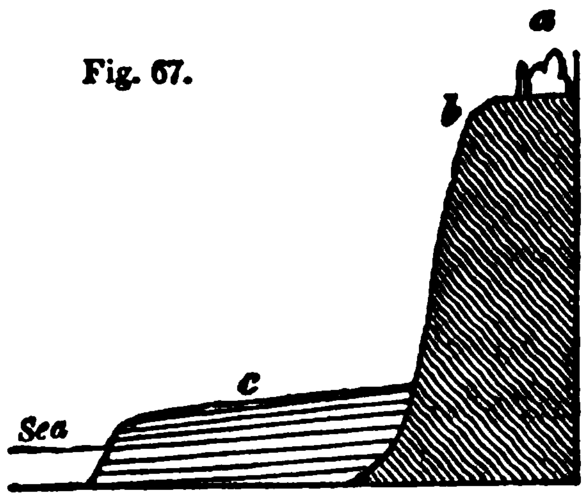
Coast south of Puzzuoli.—If we coast along the shore from Naples to Puzzuoli, we find, on approaching the latter place, that the lofty and precipitous cliffs of indurated tuff, resembling that of which Naples is built, retire slightly from the sea; and that a low level tract of fertile land, of a very different aspect, intervenes between the present sea-beach and what was evidently the ancient line of coast.

The inland cliff may be seen opposite the small island of Nisida, about two miles and a half south-east of Puzzuoli*, where, at the height of thirty-two feet above the level of the sea, Mr. Babbage observed an

* See Map, p. 149. Pl. VII. Fig. 2.

ancient mark, such as might have been worn by the waves; and, upon further examination, discovered that, along that line, the face of the perpendicular rock, consisting of very hard tuff, was covered with barnacles (*Balanus sulcatus*, Lamk.), and drilled by boring testacea. Some of the hollows of the lithodomi contained the shells; while others were filled with the valves of a species of Arca.* Nearer to Puzzuoli, the inland cliff is eighty feet high, and as perpendicular as if it was still undermined by the waves. At its

Fig. 67.



a, Antiquities on hill S. E. of Puzzuoli.
b, Ancient cliff now inland.
c, Terrace composed of recent submarine deposit.

base, a new deposit, consituting the fertile tract above alluded to, attains a height of about twenty feet above the sea; and, since it is composed of regular sedimentary deposits, containing marine shells, its position proves that, subsequently to its formation, there has been a change of more than twenty feet in the relative level of land and sea.

The sea encroaches on these new incoherent strata; and as the soil is valuable, a wall has been built for its

* Mr. Babbage examined this spot in company with Mr. Head, in June, 1828, and has shown me numerous specimens of the shells collected here, and in the Temple of Serapis.

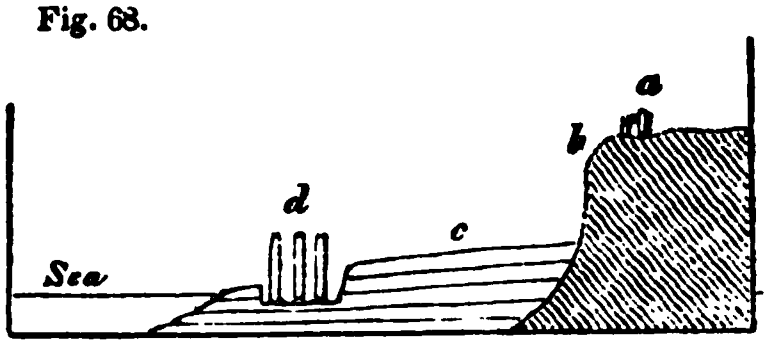
protection: but when I visited the spot in 1828, the waves had swept away part of this rampart, and exposed to view a regular series of strata of tuff, more or less argillaceous, alternating with beds of pumice and lapilli, and containing great abundance of marine shells, of species now common on this coast, and amongst them *Cardium rusticum*, *Ostrea edulis*, *Donax trunculus*, Lamk., and others. The strata vary from about a foot to a foot and a half in thickness, and one of them contains abundantly remains of works of art, tiles, squares of mosaic pavement of different colours, and small sculptured ornaments, perfectly uninjured. Intermixed with these I collected some teeth of the pig and ox. These fragments of building occur below as well as above strata containing marine shells. Puzzuoli itself stands chiefly on a promontory of the older tufaceous formation, which cuts off the new deposit, although I detected a small patch of the latter in a garden under the town.

From the town the ruins of a mole, called Caligula's Bridge, run out into the sea. This mole consists of a number of piers and arches; and Mr. Babbage found, on the sixth pier, perforations of lithodomi four feet above the level of the sea; and near the termination of the mole, on the last pier but one, marks of the same ten feet above the level of the sea, together with great numbers of balani and flustra.

Coast north of Puzzuoli.—If we then pass to the north of Puzzuoli, and examine the coast between that town and Monte Nuovo, we find a repetition of analogous phenomena. The sloping sides of Monte Barbaro slant down within a short distance of the coast, and terminate in an inland cliff of moderate elevation, to which the geologist perceives at once that the sea

must, at some former period, have extended. Between this cliff and the sea is a low plain or terrace, called La Starza, corresponding to that before described on the south-east of the town; and as the sea encroaches rapidly, fresh sections of the strata may readily be obtained, of which the annexed is an example.

Fig. 68.



a, Remains of Cicero's villa, N. side of Puzzuoli.*
b, Ancient cliff now inland.
c, Terrace composed of recent submarine deposits.
d, Temple of Serapis.

Section on the shore north of the town of Puzzuoli:—

	Ft.	In.
1. Vegetable soil - - - - - -	1	0
2. Horizontal beds of pumice and scoriæ, with broken fragments of unrolled bricks, bones of animals, and marine shells - - - -	1	6
3. Beds of lapilli, containing abundance of marine shells, principally *Cardium rusticum*, *Donax trunculus*, Lam., *Ostrea edulis*, *Triton cutaceum*, Lam. and *Buccinum serratum*, Brocchi, the beds varying in thickness from one to eighteen inches - - -	10	0
4. Argillaceous tuff, containing bricks and fragments of buildings not rounded by attrition	1	6

* The spot here indicated on the summit of the cliff is that from which Hamilton's view, plate 26., Campi Phlegræi, is taken, and on which, he observes, Cicero's villa, called the Academia, anciently stood.

The thickness of many of these beds varies greatly as we trace them along the shore, and sometimes the whole group rises to a greater height than at the point above described. The surface of the tract which they compose appears to slope gently upwards towards the base of the old cliffs.

Now, if these appearances presented themselves on the eastern or southern coast of England, a geologist would naturally endeavour to seek an explanation in some local depression of high-water mark, in consequence of a change in the set of the tides and currents: for towns have been built, like ancient Brighton, on sandy tracts intervening between the old cliff and the sea, and, in some cases, they have been finally swept away by the return of the ocean. On the other hand, the inland cliff at Lowestoffe, in Suffolk, remains, as was before stated, at some distance from the shore, and the low green tract called the Ness may be compared to the low flat called La Starza, near Puzzuoli.* But there are scarce any tides in the Mediterranean; and, to suppose that sea to have sunk generally from twenty to twenty-five feet since the shores of Campania were covered with sumptuous buildings, is an hypothesis obviously untenable. The observations, indeed, made during modern surveys on the moles and cothons (docks) constructed by the ancients in various ports of the Mediterranean, have proved that there has been no sensible variation of level in that sea during the last two thousand years.†

Thus we arrive, without the aid of the celebrated temple, at the conclusion, that the recent marine deposit at Puzzuoli was upraised in modern times above

* See Vol. II. p. 57.

† On the authority of Captain W. H. Smyth, R. N.

the level of the sea, and that not only this change of position, but the accumulation of the modern strata, was posterior to the destruction of many edifices, of which they contain the imbedded remains. If we now examine the evidence afforded by the temple itself, it appears, from the most authentic accounts, that the three pillars now standing erect continued, down to the middle of the last century, half buried in the new marine strata before described. The upper part of the columns, being concealed by bushes, had not attracted, until the year 1749, the notice of antiquaries; but, when the soil was removed in 1750, they were seen to form part of the remains of a splendid edifice, the pavement of which was still preserved, and upon it lay a number of columns of African breccia and of granite. The original plan of the building could be traced distinctly; it was of a quadrangular form, seventy feet in diameter, and the roof had been supported by forty-six noble columns, twenty-four of granite, and the rest of marble. The large court was surrounded by apartments, supposed to have been used as bathing-rooms; for a thermal spring, still used for medicinal purposes, issues now just behind the building, and the water, it is said, of this spring was conveyed by marble ducts into the chambers.

Many antiquaries have entered into elaborate discussions as to the deity to which this edifice was consecrated; but Signor Carelli, who has written the last able treatise on the subject,* endeavours to show that all the religious edifices of Greece were of a form essentially different; that the building, therefore, could never have been a temple; that it corresponded to the public bathing-rooms at many of our watering-places;

* Dissertazione sulla Sagra Architettura degli Antichi.

and, lastly, that if it had been a temple, it could not have been dedicated to Serapis, the worship of the Egyptian god being strictly prohibited, at the time when this edifice was in use, by the senate of Rome.

Perforation of the columns by lithodomous shells. — It is not for the geologist to offer an opinion on these topics; and I shall, therefore, designate this valuable relic of antiquity by its generally received name, and proceed to consider the memorials of physical changes inscribed on the three standing columns in most legible characters by the hand of Nature. (See Frontispiece, Vol. I.*) These pillars, which have been carved each out of a single block of marble, are forty-two feet in height. An horizontal fissure nearly intersects one of the columns; the other two are entire. They are all slightly out of the perpendicular, inclining somewhat to the south-west, that is, towards the sea.† Their surface is smooth and uninjured to the height of about twelve feet above their pedestals. Above this is a zone, about nine feet in height, where the marble has been pierced by a species of marine perforating bivalve — *Lithodomus*, Cuv.‡ The holes of these animals are pear-shaped, the external opening being minute, and gradually increasing downwards. At the

* This view of the present state of the temple has been reduced from that of the Canonico Andrea de Jorio, Ricerche sul Tempio di Serapide, in Puzzuoli. Napoli, 1820.

† This appears from the measurement of Captain Basil Hall, R. N., Proceedings of Geol. Soc., No. 38, p. 114. The fact of the three standing columns having been each formed out of a single stone was first pointed out to me by Mr. James Hall, and is important, as helping to explain why they were not shaken down.

‡ *Modiola lithophaga*, Lam. *Mytilus lithophagus*, Linn.

bottom of the cavities, many shells are still found, notwithstanding the great numbers that have been taken out by visitors; in many the valves of a species of arca, an animal which conceals itself in small hollows, occur. The perforations are so considerable in depth and size, that they manifest a long-continued abode of the lithodomi in the columns; for, as the inhabitant grows older and increases in size, it bores a large cavity, to correspond with the increasing magnitude of its shell. We must, consequently, infer a long-continued immersion of the pillars in sea-water, at a time when the lower part was covered up and protected by strata of tuff and the rubbish of buildings; the highest part, at the same time, projecting above the waters, and being consequently weathered, but not materially injured.

On the pavement of the temple lie some columns of marble, which are perforated in the same manner in certain parts; one, for example, to the length of eight feet, while, for the length of four feet, it is uninjured. Several of these broken columns are eaten into, not only on the exterior, but on the cross fracture, and, on some of them, other marine animals have fixed themselves.* All the granite pillars are untouched by lithodomi. The platform of the temple, which is not perfectly even, is at present (1828) about one foot below high-water mark (for there are small tides in the Bay of Naples); and the sea, which is only one hundred feet distant, soaks through the intervening soil. The upper part of the perforations, then, are at least twenty-three feet above high-water mark; and it is

* *Serpula contortuplicata*, Linn., and *Vermilia triquetra*, Lam. These species, as well as the *Lithodomus*, are now inhabitants of the neighbouring sea.

clear that the columns must have continued for a long time in an erect position, immersed in salt water. After remaining for many years submerged, they must have been upraised to the height of about twenty-three feet above the level of the sea.

Temples and Roman roads under water.— So far the information derived from the temple corroborates that before obtained from the new strata in the plain of La Starza, and proves nothing more. But, as the temple could not have been built originally at the bottom of the sea, it must have first sunk down below the waves, and afterwards have been elevated. Of such subsidences there are numerous independent proofs in the Bay of Baiæ. Not far from the shore, to the north-west of the Temple of Serapis, are the ruins of a temple of Neptune, and a temple of the Nymphs, now under water. The columns of the former edifice stand erect in five feet water, their upper portions just rising to the surface of the sea. The pedestals are doubtless buried in the mud; so that if this part of the bottom of the bay should hereafter be elevated, the exhumation of this temple might take place after the manner of that of Serapis. Both these buildings probably participated in the movement which raised the Starza; but, either they were deeper under water than the Temple of Serapis, or they were not raised up again to so great a height. There are also two Roman roads under water in the bay, one reaching from Puzzuoli towards the Lucrine Lake, which may still be seen, and the other near the Castle of Baiæ. The ancient mole, too, of Puzzuoli, before alluded to, has the water up to a considerable height of the arches; whereas Brieslak justly observes, it is next to certain that the piers must formerly have reached the

surface before the springing of the arches;* so that, although the phenomena before described prove that this mole has been uplifted ten feet above the level at which it once stood, it is still evident that it has not yet been restored to its original position.

A modern writer also reminds us, that these effects are not so local as some would have us to believe; for on the opposite side of the Bay of Naples, on the Sorrentine coast, which, as well as Puzzuoli, is subject to earthquakes, a road, with some fragments of Roman buildings, is covered to some depth by the sea. In the island of Capri, also, which is situated some way at sea, in the opening of the Bay of Naples, one of the palaces of Tiberius is now covered with water.† They who have attentively considered the effects of earthquakes, before enumerated, as having occurred during the last 150 years, will not feel astonished at these signs of alternate elevation and depression of the bed of the sea and the adjoining coast during the course of eighteen centuries; but, on the contrary, they will be very much astonished if future researches fail to bring to light similar indications of change in almost all regions of volcanic disturbances.

That buildings should have been submerged, and afterwards upheaved, without being entirely reduced to a heap of ruins, will appear no anomaly, when we recollect that, in the year 1819, when the delta of the Indus sank down, the houses within the fort of Sindree

* Voy. dans la Campanie, tome ii. p. 162.

† Mr. Forbes, Physical Notices of the Bay of Naples. Ed. Journ. of Sci., No. II., new series, p. 280. October, 1829. When I visited Puzzuoli, and arrived at the above conclusions, I knew nothing of Mr. Forbes's observations, which I first saw on my return to England the year following.

subsided beneath the waves, without being overthrown. In like manner, in the year 1692, the buildings around the harbour of Port Royal, in Jamaica, descended suddenly to the depth of between thirty and fifty feet under the sea without falling. Even on small portions of land transported to a distance of a mile, down a declivity, tenements, like those near Mileto, in Calabria, were carried entire. At Valparaiso buildings were left standing in 1822, when their foundations, together with a long tract of the Chilian coast, were permanently upraised to the height of several feet. It is still more easy to conceive that an edifice may escape falling during the upheaval or subsidence of land, if the walls are supported on the exterior and interior with a deposit, like that which surrounded and filled to the height of ten or twelve feet the Temple of Serapis at Puzzuoli.

Periods when the Temple of Serapis sank and rose.— The next subject of inquiry is the era when these remarkable changes took place in the Bay of Baiæ. It appears that, in the Atrium of the Temple of Serapis, inscriptions were found in which Septimius Severus and Marcus Aurelius record their labours in adorning it with precious marbles.* We may, therefore, conclude that it existed at least down to the third century of our era nearly in its original position; and it may have been built at the close of the second century. On the other hand, we have evidence that the marine deposit forming the flat land, called La Starza, was still covered by the sea in the year 1530, or just eight years anterior to the tremendous explosion of Monte Nuovo. Mr. Forbes has lately pointed out the

* Brieslak, Voy. dans la Campanie, tom. ii. p. 167.

distinct testimony of an old Italian writer, Loffredo, in confirmation of this important point.* Writing in 1580, Loffredo declares that, fifty years previously, the sea washed the base of the hills which rise from the flat land before alluded to; and at that time, he expressly tells us, a person *might have fished* from the site of those ruins which are now called the Stadium. (See p. 385. Fig. 66.) Hence it follows, that the subsidence of the ground happened at some period between the third century, when the temple was still standing, and the beginning of the sixteenth century, when its site was still submerged.

Now, in this interval, the only two events which are recorded in the imperfect annals of the dark ages are, the eruption of the Solfatara in 1198, and an earthquake in 1488, by which Puzzuoli was ruined. It is at least highly probable, that earthquakes, which preceded the eruption of the Solfatara, which is very near the temple (see p. 385. Fig. 66.) caused a subsidence, and the pumice and other matters ejected from that volcano might have fallen in heavy showers into the sea, and would thus immediately have covered up the lower part of the columns, and preserved them from the action of the sea and from lithodomous perforations. The waves might afterwards have thrown down many pillars, and formed strata of broken fragments of buildings, intermixed with volcanic ejections, and thus have caused those strata, containing works of art and shells, which extend for several miles along the coast. Mr. Babbage, after carefully examining several incrustations of carbonate of lime, such as the waters of the hot spring might have deposited, adhering to

* Ed. Journ. of Science, new series, No. II. p. 281.

the walls and columns of the temple at different heights, as also the distinct marks of ancient lines of water-level, visible below the zone of lithophagous perforations, has come to the conclusion, and I think, proved, that the subsidence of the building was not sudden, or at one period only, but gradual, and by successive movements.*

As to the re-elevation of the depressed tract, that may also have occurred at different periods, since earthquakes are not unfrequent in this country. Jorio cites two authentic documents in illustration of this point. The first, dated Oct. 1503, is a deed, written in Italian, by which Ferdinand and Isabella grant to the University of Puzzuoli a portion of land, "where the sea is drying up" (che va seccando el mare); the second, a document in Latin, dated May 23. 1511, or nearly eight years after, by which Ferdinand grants to the city a certain territory around Puzzuoli, where the ground *is dried up* from the sea (desiccatum).†

It is perfectly evident, however, from Loffredo's statement, that the principal elevation of the low tract called La Starza took place after the year 1530, and some time before the year 1580; and from this alone we might have suspected that the change happened in the year 1538, when Monte Nuovo was formed. But, fortunately, we are not left in the slightest doubt that such was the date of this remarkable event; for in the descriptions before cited (p. 160.) of Falconi and Toledo of the convulsion of 1538, of which they were eye-witnesses, we find an express statement of the sea having abandoned a considerable tract of the shore, so that fish were taken by the inhabitants; and among

* Proceedings of Geol. Soc., No. 36. March, 1834.

† Sul Tempio di Serap. chap. viii.

other things Falconi mentions that he saw two springs *in the newly discovered ruins.*

Encroachments of the sea in the Bay of Baiæ.—The flat land, when first upraised, must have been more extensive than now, for the sea encroaches somewhat rapidly, both to the north and south-east of Puzzuoli. The coast has, of late years, given way more than a foot in a twelvemonth; and I was assured, by fishermen in the bay, that it has lost ground near Puzzuoli, to the extent of thirty feet, within their memory. By this gradual encroachment, the whole of the low land near the temple may perhaps, in the course of time be carried away, unless some new upheaval of the country shall take place, before the waves reach the ancient coast-line; but the removal of this narrow tract will by no means restore the country to its former state, for the old tufaceous hills, and the interstratified current of trachytic lava which has flowed from the Solfatara, must have participated in the movement of 1538; and these will remain upraised, even though the sea may regain its ancient limits.

It appears, however, from the recent memoir of Niccolini, published in 1838, that since the beginning of the 19th century, the Temple of Serapis has subsided more than two feet. That learned architect visited the ruins frequently, for the sake of making drawings, in the beginning of the year 1807, and was in the habit of remaining there throughout the day, yet never saw the pavement overflowed by the sea, except occasionally when the south wind blew violently. On his return, sixteen years after, to superintend some excavations ordered by the King of Naples, he found the pavement covered by sea-water twice every day at high tide, so that he was obliged to place there a

line of stones to stand upon. This induced him to make a series of observations with a hydrometer from Oct. 1822 to July 1838, by which means he ascertained that the ground has been and is sinking, at the average rate of about seven millimetres a year, or about one inch in four years; so that in 1838, fish were caught every day on that part of the pavement where, in 1807, there was never a drop of water in calm weather.*

By the excavations carried on in 1828, below the marble pavement of the temple, another costly pavement of mosaic was found, at the depth of about six feet below the other. The existence of these two pavements, at different levels, clearly implies some subsidence previously to all the changes already alluded to, which had rendered it necessary to construct a new floor at a higher level. From this fact, and from other analogous proofs, derived chiefly from the architectural investigations of Niccolini, we may infer that the soil forming the foundation of the Temple of Serapis has, in the course of the last nineteen centuries, undergone the following oscillations: — First, about eighty years before the Christian era, when the ancient mosaic pavement was constructed, it was about twelve feet *above* its actual level, or that at which it stood in 1838; secondly, towards the close of the first century after Christ, it was only six feet above its actual level; thirdly, by the end of the fourth century, it had nearly subsided to its present level; fourthly, in the middle ages, and before the eruption of Monte Nuovo, it was about nineteen feet *below* its present level; lastly, at the beginning of the present century, it was about two feet two inches above the level at which it now stands in 1838.

* Tavola Metrica Chronologica, &c. Napoli, 1838.

Signor Niccolini has, indeed, embraced the opinion that it is the sea which has risen and fallen, which Signor Capocci has successfully controverted, appealing to many appearances which attest the local character of the movements of the adjoining country, besides the historical fact, that in 1538, when the sea retired permanently 200 yards from the ancient shore at Puzzuoli, there was no simultaneous retreat of the waters from Naples, Castelamare, and Ischia.*

Mr. Babbage had arrived, as I before stated, by perfectly independent evidence, drawn from ancient calcareous deposits of the hot spring within the area of the temple, and from marine deposits associated with the same, and from lines of water-level at various heights, to the conclusion, that the subsidence of the temple was gradual, and that it continued until the pavement was at least nineteen feet below the level of the sea.†

Permanence of the ocean's level.—In concluding this subject, I may observe, that the interminable controversies to which the phenomena of the Bay of Baiæ gave rise, have sprung from an extreme reluctance to admit that the land, rather than the sea, is subject alternately to rise and fall. Had it been assumed that the level of the ocean was invariable, on the ground that no fluctuations have as yet been clearly established, and that, on the other hand, the continents are inconstant in their level, as has been demonstrated by the most unequivocal proofs again and again, from the time of Strabo to our own times, the appearances of the Temple at Puzzuoli could never have been regarded as enigmatical. Even if contemporary accounts had not distinctly attested the upraising of the

* Nuove Ricerche sul Temp. di Serap.

† Proceedings Geol. Soc. vol. ii. p. 78.

coast, this explanation should have been proposed in the first instance as the most natural, instead of being now adopted unwillingly when all others have failed.

To the strong prejudices still existing in regard to the mobility of the land, we may attribute the rarity of such discoveries as have been recently brought to light in the Bay of Baiæ and the Bay of Conception. A false theory, it is well known, may render us blind to facts which are opposed to our prepossessions, or may conceal from us their true import when we behold them. But it is time that the geologist should, in some degree, overcome those first and natural impressions which induced the poets of old to select the rock as the emblem of firmness — the sea as the image of inconstancy. Our modern poet, in a more philosophical spirit, saw in the sea "The image of eternity," and has finely contrasted the fleeting existence of the successive empires which have flourished and fallen on the borders of the ocean with its own unchanged stability.

——— Their decay
Has dried up realms to deserts: — not so thou,
Unchangeable, save to thy wild waves' play:
Time writes no wrinkle on thine azure brow;
Such as creation's dawn beheld, thou rollest now.

CHILDE HAROLD, Canto IV.

CHAPTER XVIII.

ELEVATION AND SUBSIDENCE OF LAND WITHOUT EARTHQUAKES.

Changes in the relative level of land and sea in regions not volcanic — Opinion of Celsius that the waters of the Baltic Sea and Northern Ocean were sinking — Objections raised to his opinion — Proofs of the stability of the sea-level in the Baltic — Playfair's hypothesis that the land was rising in Sweden — Opinion of Von Buch — Marks cut on the rocks — Survey of these in 1820 — Facility of detecting slight alterations in level of sea on coast of Sweden — Shores of the ocean also rising — Area upheaved — Shelly deposits of Uddevalla — Of Stockholm, containing fossil shells characteristic of the Baltic — Subsidence in South of Sweden — Fishing-hut buried under marine strata — Sinking of land in Greenland — Bearing of these facts on geology.

We have now considered the phenomena of volcanos and earthquakes according to the division of the subject before proposed (p. 120.), and have next to turn our attention to those slow and insensible changes in the relative level of land and sea which take place in countries remote from volcanos, and where no violent earthquakes have occurred within the period of human observation. Early in the last century the Swedish naturalist, Celsius, expressed his opinion that the waters, both of the Baltic and Northern Ocean, were gradually subsiding. From numerous observations he inferred, that the rate of depression was about forty

Swedish inches in a century.* In support of this position, he alleged that there were many rocks both on the shores of the Baltic and the ocean known to have been once sunken reefs, and dangerous to navigators, but which were in his time above water — that the waters of the Gulf of Bothnia had been gradually converted into land, several ancient ports having been changed into inland cities, small islands joined to the continent, and old fishing grounds deserted as being too shallow, or entirely dried up. Celsius also maintained, that the evidence of the change rested not only on modern observations, but on the authority of the ancient geographers, who had stated that Scandinavia was formerly an island. This island, he argued, must in the course of centuries, by the gradual retreat of the sea, have become connected with the continent; an event which he supposed to have happened after the time of Pliny, and before the ninth century of our era.

To this argument it was objected that the ancients were so ignorant of the geography of the most northern parts of Europe, that their authority was entitled to no weight; and that their representation of Scandinavia as an island, might with more propriety be adduced to prove the scantiness of their information, than to confirm so bold an hypothesis. It was also remarked, that if the land which connected Scandinavia with the main continent was laid dry between the time of Pliny and the ninth century, to the extent to which it is known to have risen above the sea at the latter period, the rate of depression could not have been uniform, as

* The Swedish measure scarcely differs from ours; the foot being divided into twelve inches, and being less than ours by three eighths of an inch only.

was pretended; for it ought to have fallen much more rapidly between the ninth and eighteenth centuries.

Many of the proofs relied on by Celsius and his followers were immediately controverted by several philosophers, who saw clearly that a fall of the sea in any one region could not take place without a general sinking of the waters over the whole globe; they denied that this was the fact, or that the depression was universal, even in the Baltic. In proof of the stability of the level of that sea, they appealed to the position of the island of Saltholm, not far from Copenhagen. This island is so low that, in autumn and winter it is permanently overflowed; and it is only dry in summer, when it serves for pasturing cattle. It appears, from documents of the year 1280, that Saltholm was then also in the same state, and exactly on a level with the mean height of the sea, instead of having been about twenty feet under water, as it ought to have been, according to the computation of Celsius. Several towns, also, on the shores of the Baltic, as Lubeck, Wismar, Rostock, Stralsund, and others, after six and even eight hundred years, are as little elevated above the sea as at the era of their foundation, being now close to the water's edge. The lowest part of Dantzic was no higher than the mean level of the sea in the year 1000; and after eight centuries its relative position remains exactly the same.*

Several of the examples of the gain of land and shallowing of the sea pointed out by Celsius, and afterwards by Linnæus, who embraced the same opinions, were ascribed by others to the deposition of

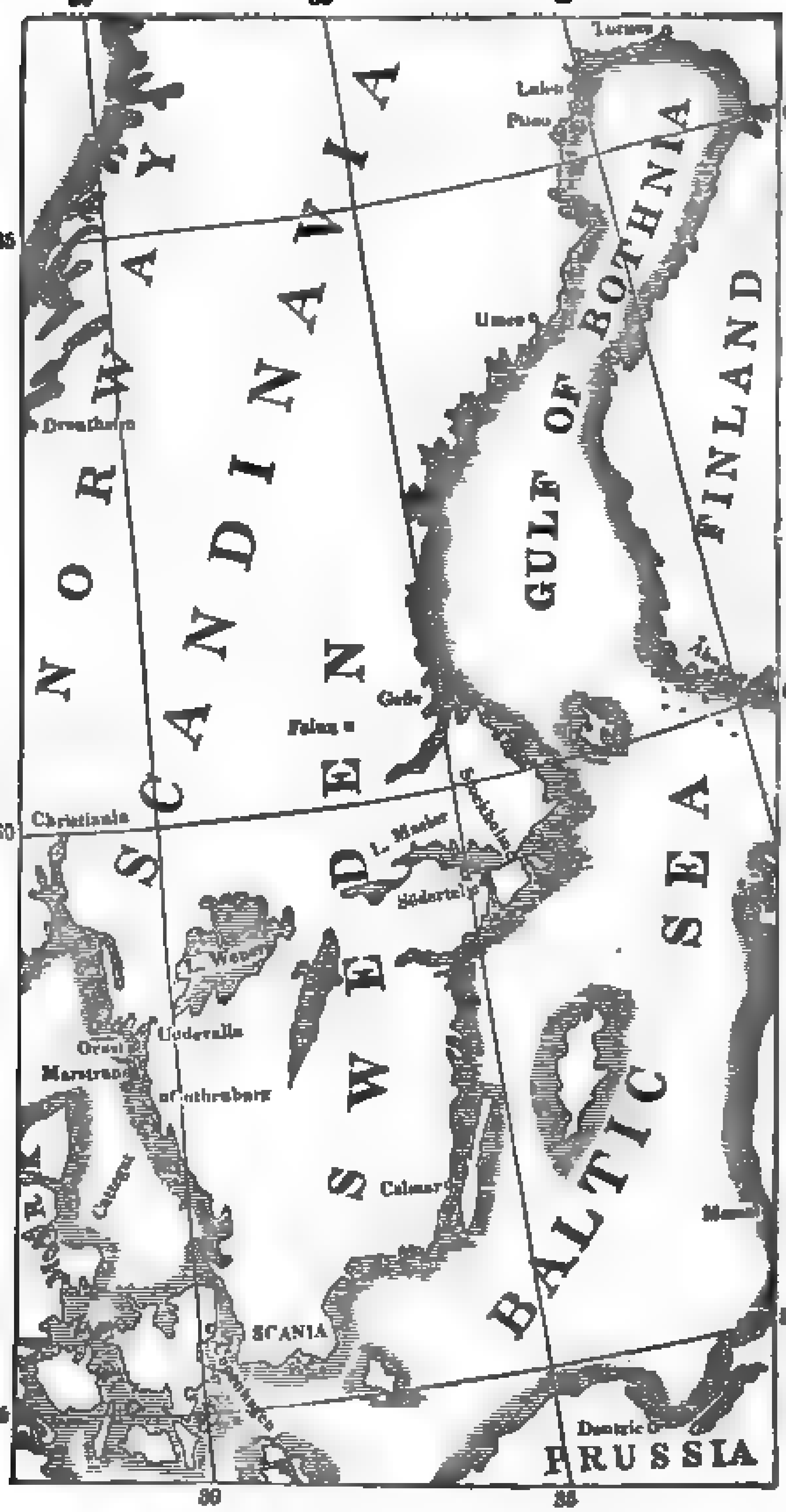
* For a full account of the Celsian controversy, we may refer our readers to Von Hoff, Geschichte, &c. vol. i. p. 439.

sediment at points where rivers entered; and, undoubtedly, Celsius had not sufficiently distinguished between changes due to these causes and such as would arise if the waters of the ocean itself were diminishing. Many large rivers descending from a mountainous country, at the head of the Gulf of Bothnia, enter the sea charged with sand, mud, and pebbles; and it was said that in these places the low land had advanced rapidly, especially near Torneo. At Piteo also, half a mile had been gained in forty-five years; at Luleo,* no less than a mile in twenty-eight years; facts which might all be admitted consistently with the assumption that the level of the Baltic has remained unchanged, like that of the Adriatic, during a period when the plains of the Po and the Adige have greatly extended their area.

It was also alleged that certain insular rocks, once entirely covered with water, had at length protruded themselves above the waves, and grown, in the course of a century and a half, to be eight feet high. The following attempt was made to explain away this phenomenon:—In the Baltic, large erratic blocks, as well as sand and smaller stones which lie on shoals, are liable every year to be frozen into the ice, where the sea freezes to the depth of five or six feet. On the melting of the snow in spring, when the sea rises about half a fathom, numerous ice-islands float away, bearing up these rocky fragments so as to convey them to a distance; and if they are driven by the waves upon shoals, they may convert them into islands by deposit-

* Piteo, Luleo, and Obo are spelt, in many English maps, Pitea, Lulea, Abo; the *a* is not sounded in the Swedish diphthong *ao* or *å*.

Fig. 88.



NORWAY
SCANDINAVIA
SWEDEN
GULF OF BOTHNIA
FINLAND
BALTIC SEA
PRUSSIA
SCANIA
Torneo
Lulea
Piteo
Umeo
Drontheim
Gefle
Falun
Christiania
L. Mælar
Stockholm
Södertelje
L. Wener
Uddevalla
Orust
Marstrand
Gothenburg
Cattegat
Calmar
Dantzic

ing the blocks; if stranded upon low islands, they may considerably augment their height.

Browallius, also, and some other Swedish naturalists, affirmed that some islands were lower than formerly; and that, by reference to this kind of evidence, there was equally good reason for contending that the level of the Baltic was gradually rising. They also added another curious proof of the permanency of the water-level, at some points at least, for many centuries. On the Finland coast were some large pines, growing close to the water's edge; these were cut down, and, by counting the concentric rings of annual growth, as seen in a transverse section of the trunk, it was demonstrated that they had stood there for four hundred years. Now, according to the Celsian hypothesis, the sea had sunk about fifteen feet during that period, in which case the germination and early growth of these pines must have been, for many seasons, below the level of the water. In like manner it was asserted, that the lower walls of many ancient castles, such as those of Sonderburg and Åbo, reached then to the water's edge, and must, therefore, according to the theory of Celsius, have been originally constructed below the level of the sea.

In reply to this last argument, Colonel Hällstrom, a Swedish engineer, well acquainted with the Finland coast, assured me, that the base of the walls of the Castle of Åbo is now ten feet above the water, so that there may have been a considerable rise of the land at that point since the building was erected.

Playfair, in his "Illustrations of the Huttonian Theory," in 1802, admitted the sufficiency of the proofs adduced by Celsius, but attributed the change of level to the movement of the land, rather than to a diminu-

tion of the waters. He observed, "that in order to depress or elevate the absolute level of the sea, by a given quantity, in any one place, we must depress or elevate it by the same quantity over the whole surface of the earth; whereas no such necessity exists with respect to the elevation or depression of the land." * The hypothesis of the rising of the land, he adds, "agrees well with the Huttonian theory, which holds, that our continents are subject to be acted upon by the expansive forces of the mineral regions; that by these forces they have been actually raised up, and are sustained by them in their present situation." †

In the year 1807, Von Buch, after returning from a tour in Scandinavia, announced his conviction, "that the whole country, from Frederickshall in Norway to Åbo in Finland, and perhaps as far as St. Petersburg, was slowly and insensibly rising." He also suggested "that Sweden may rise more than Norway, and the northern more than the southern part." ‡ He was led to these conclusions principally by information obtained from the inhabitants, and pilots, and in part by the occurrence of marine shells of recent species, which he had found at several points on the coast of Norway above the level of the sea. He also mentions the marks set on the rocks. Von Buch, therefore, has the merit of being the first geologist who, after a personal examination of the evidence, declared in favour of the rise of land in Scandinavia.

The attention excited by this subject in the early part of the last century, induced many philosophers in Sweden to endeavour to determine, by accurate observations, whether the standard level of the Baltic

* Sect. 393.

† Sect. 398.

‡ Transl. of his Travels, p. 387.

was really subject to periodical variations; and under their direction, lines or grooves, indicating the ordinary level of the water on a calm day, together with the date of the year, were chiselled out upon the rocks. In 1820–21, all the marks made before those years were examined by the officers of the pilotage establishment of Sweden; and in their report to the Royal Academy of Stockholm they declared, that on comparing the level of the sea at the time of their observations with that indicated by the ancient marks, they found that the Baltic was lower relatively to the land in certain places, but the amount of change during equal periods of time had not been every where the same. During their survey, they cut new marks for the guidance of future observers, several of which I had an opportunity of examining fourteen years after (in the summer of 1834), and in that interval the land appeared to me to have risen at certain places north of Stockholm four or five inches. I also convinced myself, during my visit to Sweden, after conversing with many civil engineers, pilots, and fishermen, and after examining some of the ancient marks, that the evidence formerly adduced in favour of the change of level, both on the coasts of Sweden and Finland, was full and satisfactory.* The alteration of level evidently diminishes as we proceed from the northern parts of the Gulf of Bothnia towards the south, being very slight around Stockholm. Some writers have indeed represented the rate of depression of the waters at

* In former editions I expressed many doubts as to the validity of the proofs of a gradual rise of land in Sweden. A detailed statement of the observations which I made in 1834, and which led me to change my opinion, will be found in the Philosophical Transactions for 1835, part i.

Stockholm as very considerable, because certain houses in that city which are built on piles have sunk down within the memory of persons still living, so as to be out of the perpendicular; and this in consequence of the tops of the piles giving way, and decaying, owing to a fall of the waters which has exposed them to be alternately wet and dry. The houses alluded to are situated on the borders of Lake Maeler, a large lake, the outlet of which joins the Baltic in the middle of Stockholm. This lake is certainly lower than formerly; but the principal cause of the change is not the elevation of the land, but the removal of two old bridges built on piles, which formerly obstructed the discharge of the fresh-water into the sea. Another cause is the opening, in the year 1819, of a new canal at Södertelje, a place south of Stockholm, by means of which a new line of communication was formed between Lake Maeler and the Baltic.*

It will naturally be asked, whether the mean level of a sea like the Baltic can ever be determined so exactly as to permit us to appreciate a variation of level, amounting only to one or two feet. In reply, I may observe, that, except near the Cattegat, there are no tides in the Baltic; and it is only when particular winds have prevailed for several days in succession, or at certain seasons when there has been an unusually abundant influx of river water, or when these causes have combined, that this sea is made to rise two or three feet above its standard level. The fluctuations due to these causes are nearly the same from year to year; so that the pilots and fishermen believe, and

* See Professor Johnston's Paper, Ed. New Phil. Journ., No. 29., July 1833; and my remarks, Phil. Trans. 1835, p. 12.

apparently with reason, that they can mark a deviation, even of a few inches, from the ordinary or mean height of the waters.

There are, moreover, peculiarities in the configuration of the shores of Norway and Sweden, which facilitate, in a remarkable degree, the appreciation of slight changes in the relative level of land and water. It has often been said, that there are two coasts, an inner and an outer one; the inner being the shore of the mainland; the outer one, a fringe of countless rocky islands of all dimensions, called the skär (*shair*). Boats and small vessels make their coasting voyages within this skär; for here they may sail in smooth water, even when the sea without is strongly agitated. But the navigation is very intricate, and the pilot must possess a perfect acquaintance with the breadth and depth of every narrow channel, and the position of innumerable sunken rocks. If on such a coast the land rises one or two feet in the course of half a century, the minute topography of the skär is entirely altered. To a stranger, indeed, who revisits it after an interval of many years, its general aspect remains the same; but the inhabitant finds that he can no longer penetrate with his boat through channels where he formerly passed; and he can tell of countless other changes in the height and breadth of isolated rocks, now exposed, but once only seen through the clear water.

The rocks of gneiss, mica-schist, and quartz, are usually very hard on this coast, slow to decompose, and, when protected from the breakers, remaining for ages unaltered in their form. Hence it is easy to mark the stages of their progressive emergence by the aid of natural and artificial marks imprinted on them.

Besides the summits of *fixed* rocks, there are numerous erratic blocks of vast size strewed over the shoals and islands in the skär, which have been probably drifted by ice in the manner before suggested.* All these are observed to have increased in height and dimensions within the last half century. Some, which were formerly known as dangerous sunken rocks, are now only hidden when the water is highest. On their first appearance, they usually present a smooth, bare, rounded protuberance, a few feet or yards in diameter; and a single sea-gull often appropriates to itself this resting-place, resorting there to devour its prey. Similar points, in the mean time, have grown to long reefs, and are constantly whitened by a multitude of sea-fowl; while others have been changed from a reef, annually submerged, to a small islet, on which a few lichens, a fir-seedling, and a few blades of grass, attest that the shoal has at length been fairly changed into dry land. Thousands of wooded islands around show the greater alterations which time can work. In the course of centuries also, the spaces intervening between the existing islands may be laid dry, and become grassy plains encircled by heights well clothed with lofty firs. This last step of the process, by which long fiords and narrow channels, once separating wooded islands, are deserted by the sea, has been exemplified within the memory of living witnesses on several parts of the coast.

Had the apparent fall of the waters been observed in the Baltic only, we might have endeavoured to explain the phenomenon by local causes affecting that sea alone. For instance, the channel by which the

* See p. 405.; also Vol. I. Book II. Chap. III.

Baltic discharges its surplus waters into the Atlantic, might be supposed to have been gradually widened and deepened by the waves and currents, in which case a fall of the water, like that before alluded to in Lake Maeler, might have occurred. But the lowering of level would in that case have been uniform and universal, and the waters could not have sunk at Torneo, while they retained their former level at Copenhagen. Such an explanation is also untenable on other grounds; for it is a fact, as Celsius long ago affirmed, that the alteration of level extends to the western shores of Sweden, bordering the ocean. The signs of elevation observed between Uddevalla and Gothenburg are as well established as those on the shores of the Bothnian Gulf. Among the places where they may be studied, are the islands of Marstrand and Gulholmen, the last-mentioned locality being one of those particularly pointed out by Celsius.

The inhabitants there and elsewhere affirm, that the rate of the sinking of the sea (or elevation of land) varies in different and adjoining districts, being greatest at points where the coast is low. But in this they are deceived; for they measure the amount of rise by the area gained, which is most considerable where the land descends with a gentle slope into the sea. In the same manner, some advocates of the Celsian theory formerly appealed to the increase of lands near the mouths of rivers, not sufficiently adverting to the fact, that if the bed of the sea is rising, the change will always be most sensible where the bottom has been previously rendered shallow; whereas, at a distance from these points, where the scarped granitic cliffs plunge at once into deep water, a much greater amount

of elevation is necessary to produce an equally conspicuous change.

As to the area in northern Europe which is subject to this slow upheaving movement, we have not as yet sufficient data for estimating it correctly. It seems probable, however, that it reaches from Gothenburg to Torneo, and from thence to the North Cape, the rate of elevation increasing always as we proceed farther northwards. The two extremities of this line are more than a thousand geographical miles distant from each other; and as both terminate in the ocean, we know not how much farther the motion may be prolonged under water. As to the breadth of the tract, its limits are equally uncertain, though it evidently extends across the widest parts of the Gulf of Bothnia, and may probably stretch far into the interior, both of Sweden and Finland. Now, if the elevation continue, a larger part of the Gulf of Bothnia will be turned into land, as also more of the ocean off the west coast of Sweden between Gothenburg and Uddevalla; and, on the other hand, if the change has been going on for thousands of years at the rate of several feet in a century, large tracts of what is now land must have been submarine at periods comparatively modern. It is natural therefore to inquire whether there are any signs of the recent sojourn of the sea on districts now inland? The answer is most satisfactory.— Near Uddevalla and the neighbouring coastland, we find upraised deposits of shells belonging to species such as now live in the ocean; while on the opposite or eastern side of Sweden, near Stockholm, Gefle, and other places bordering the Bothnian Gulf, there are analogous beds containing shells of species characteristic of the Baltic.

Von Buch announced, in 1807, that he had discovered in Norway and at Uddevalla in Sweden, beds of shells of existing species, at considerable heights above the sea. Since that time, other naturalists have confirmed his observation; and, according to Ström, deposits occur at an elevation of more than 400 feet above the sea in the northern part of Norway. M. Alex. Brongniart, when he visited Uddevalla, ascertained that one of the principal masses of shells, that of Capellbacken, is raised more than 200 feet above the sea, resting on rocks of gneiss, all the species being identical with those now inhabiting the contiguous ocean. The same naturalist also stated that on examining with care the surface of the gneiss, immediately above the ancient shelly deposit, he found barnacles (*balani*) adhering to the rocks, showing that the sea had remained there for a long time. I was fortunate enough to be able to verify this observation by finding, in the summer of 1834, at Kured, about two miles north of Uddevalla, and at the height of more than 100 feet above the sea, a surface of gneiss newly laid open by the partial removal of a mass of shells used largely in the district for making lime and repairing the roads. So firmly did these barnacles adhere to the gneiss that I broke off portions of the rock with the shells attached. The face of the gneiss was also encrusted with small zoophytes (*Cellepora?* Lam.), but had these or the barnacles been exposed in the atmosphere ever since the elevation of the rocks above the sea, they would probably have decomposed and been obliterated.

The town of Uddevalla stands at the head of a narrow creek overhung by steep and barren rocks of gneiss, of which all the adjacent country is composed, except in the low grounds and bottoms of valleys,

where strata of sand, clay, and marl frequently hide the fundamental rocks. To these newer and horizontal deposits the fossil shells above mentioned belong, and similar marine remains are found at various heights above the sea on the opposite island of Orust. The extreme distance from the sea to which such fossils extend is as yet unknown, but they have been already found at Trollhättan in digging the canal there, and still farther inland on the northern borders of Lake Wener fifty miles from the sea, at an elevation of 200 feet, near Lake Rogvarpen.

To pass to the Baltic: I observed near its shores at Södertelje, sixteen miles S. W. of Stockholm, strata of sand, clay, and marl, more than 100 feet high, and containing shells of species now inhabiting the Bothnian Gulf. These consist partly of marine and partly of freshwater species; but they are few in number, the brackishness of the water appearing to be very unfavourable to the development of testacea. The most abundant species are the common cockle, and the common mussel and periwinkle of our shores (*Cardium edule*, *Mytilus edulis*, and *Littorina littorea*), together with a small tellina (*T. Baltica*), and a few minute univalves allied to *Paludina ulva*. These live in the same waters as a *Lymneus*, a *Neritina* (*N. fluviatilis*), and some other freshwater shells.

But the marine mollusks of the Baltic above mentioned, although very numerous in individuals, are dwarfish in size, scarcely ever attaining a third of the average dimensions which they acquire in the salter waters of the ocean. By this character alone a geologist would generally be able to recognize an assemblage of Baltic fossils as distinguished from those derived from a deposit in the ocean. The absence also

of oysters, barnacles, whelks, scallops, limpets, (*ostrea, balanus, buccinum, pecten, patella*), and many other forms abounding alike in the sea near Uddevalla, and in the fossiliferous deposits of modern date on that coast, supplies an additional negative character of the greatest value, distinguishing assemblages of Baltic from those of oceanic shells. Now the strata containing Baltic shells are found in many localities near Stockholm, Upsala, and Gefle, and will probably be discovered every where around the borders of the Bothnian Gulf; for I have seen similar remains brought from Finland, in marl resembling that found near Stockholm. The utmost distance to which these deposits have yet been traced inland, is on the southern shores of Lake Maeler, at a place seventy miles from the sea.* Hence it appears from the distinct assemblage of fossil shells found on the eastern and western coasts of Sweden, that the Baltic has been for a long period separated as now from the ocean, although the intervening tract of land was once much narrower, even after both seas had become inhabited by all the existing species of testacea.

As no accurate observations on the rise of the Swedish coast refer to periods more remote than a century and a half from the present time, and as traditional information, and that derived from ancient buildings on the coast, do not enable the antiquary to trace back any monuments of change for more than five or six centuries, we cannot declare whether the rate of the upheaving force is uniform during very long periods. In those districts where the fossil shells are found at the height of more than 200 feet above the ocean, as at Uddevalla, Orust, and Lake Rogvarpen,

* Phil. Trans. 1835, part i.

the present rate of rise seems less than four feet in a century. Even at that rate it would have required five thousand years to lift up those deposits. But as the movement is now very different in different places, it may also have varied much in intensity at different eras.

We have, moreover, yet to learn not only whether the motion proceeds always at the same rate, but also whether it has been uniformly *in one direction.* The level of the land may oscillate; and for centuries there may be a depression, and afterwards a re-elevation, of the same district. Some phenomena in the neighbourhood of Stockholm, appear to me only explicable on the supposition of the alternate rising and sinking of the ground since the country was inhabited by man. In digging a canal, in 1819, at Södertelje, about sixteen miles to the south of Stockholm, to unite Lake Maeler with the Baltic, marine strata, containing fossil shells of Baltic species, were passed through. At a depth of about sixty feet, they came down upon what seems to have been a buried fishing-hut, constructed of wood, in a state of decomposition, which soon crumbled away on exposure to the air. The lowest part, however, which had stood on a level with the sea, was in a more perfect state of preservation. On the floor of this hut was a rude fire-place, consisting of a ring of stones, and within this were cinders and charred wood. On the outside lay boughs of the fir, cut as with an axe, with the leaves or needles still attached. It seems impossible to explain the position of this buried hut, without imagining, as in the case of the Temple of Serapis (see p. 384.), first, a subsidence to the depth of more than sixty feet, then a re-elevation. During the period of submergence, the hut must

have become covered over with gravel and shelly marl, under which not only the hut, but several vessels also were found, of a very antique form, and having their timbers fastened together by wooden pegs instead of nails.*

Whether any of the land in Norway is now rising must be determined by future investigations. Marine fossil shells, of recent species, have been collected from inland places near Drontheim; but Mr. Everest, in his "Travels through Norway," informs us that the small island of Munkholm, which is an insulated rock in the harbour of Drontheim, affords conclusive evidence of the land having in that region remained stationary for the last eight centuries. The area of this isle does not exceed that of a small village, and by an official survey, its highest point has been determined to be twenty-three feet above the mean high water mark, that is, the mean between neap and spring tides. Now, a monastery was founded there by Canute the Great, A. D. 1028, and thirty-three years before that time it was in use as a common place of execution. According to the assumed average rate of rise in Sweden (about forty inches in a century), we should be obliged to suppose that this island had been three feet eight inches below high-water mark when it was originally chosen as the site of the monastery.

It has been already stated, that in proceeding from the North Cape to Stockholm, the rate of upheaval diminishes from several feet to a few inches in a century. To the south of Stockholm the upward movement ceases, and at length in Scania, or the southernmost part of Sweden, it appears to give place to a movement in an opposite direction. In proof of this

* See the paper before referred to, Phil. Trans. 1835, part i.

fact, Professor Nilsson observes, in the first place, that there are no elevated beds of recent marine shells in Scania like those farther to the north. Secondly, Linnæus, with a view of ascertaining whether the waters of the Baltic were retiring from the Scanian shore, measured, in 1749, the distance between the sea and a large stone near Trelleborg. This same stone was, in 1836, a hundred feet nearer the water's edge than in Linnæus's time, or eighty-seven years before. Thirdly, there is also a submerged peat moss consisting of land and freshwater plants, beneath the sea at a point to which no peat could have been drifted down by any river. Fourthly, and what is still more conclusive, it is found that in seaport towns, all along the coast of Scania, there are streets below the high-water level of the Baltic, and in some cases below the level of the lowest tide. Thus, when the wind is high at Malmö, the water overflows one of the present streets, and some years ago some excavations showed an ancient street in the same place eight feet lower, and it was then seen that there had been an artificial raising of the ground, doubtless in consequence of that subsidence. There is also a street at Trelleborg, and another at Skanör, a few inches below high-water mark, and a street at Ystad is exactly on a level with the sea, at which it could not have been originally built.

The inferences deduced from the foregoing facts are in perfect harmony with the proofs lately brought to light by two Danish investigators, Dr. Pingel and Captain Graah, of the sinking down of part of the west coast of Greenland, for a space of more than 600 miles from north to south. The observations of Captain Graah were made during a survey of Greenland in 1823–24; and afterwards in 1828–29; those by Dr.

Pingel were made in 1830–32. It appears from various signs and traditions, that the coast has been subsiding for the last four centuries from the firth called Igaliko, in lat. 60° 43′ N., to Disco Bay, extending to nearly the 69th degree of north latitude. Ancient buildings on low rocky islands and on the shore of the mainland have been gradually submerged, and experience has taught the aboriginal Greenlander never to build his hut near the water's edge. In one case, the Moravian settlers have been obliged more than once to move inland the poles upon which their large boats were set, and the old poles still remain beneath the water as silent witnesses of the change.*

The probable cause of the movements above alluded to, whether of elevation or depression, will be more appropriately discussed in the following chapters, when the origin of subterranean heat is considered. But I may remark here, that the rise of Scandinavia has naturally been regarded as a very singular and scarcely credible phenomenon, because no region on the globe has been more free within the times of authentic history from violent earthquakes. In common, indeed, with our own island, and with almost every spot on the globe, some movements have been, at different periods, experienced, both in Norway and Sweden. But some of these, as for example during the Lisbon earthquake in 1755, may have been mere vibrations of the earth's crust prolonged from a great distance. Others, however, have been sufficiently local to indicate a source of disturbance immediately under the country itself. Notwithstanding these shocks Scandinavia has, upon the whole, been as tranquil in modern times, and

* See Proceedings of Geol. Soc., No. 42. p. 208. I also conversed with Dr. Pingel on the subject at Copenhagen in 1834.

as free from subterranean convulsions, as any region of equal extent on the globe. There is also another circumstance which has made the change of level in Sweden appear anomalous, and has for a long time caused the proofs of the fact to be received with reluctance. Volcanic action, as we have seen, is usually intermittent: and the variations of level to which it has given rise have taken place by starts, not by a prolonged and insensible movement similar to that experienced in Sweden. Yet, as we enlarge our experience of modern changes, we discover instances in which the volcanic eruption, the earthquake, and the permanent rise or fall of land, whether slow or sudden, are all connected. The union of these various circumstances was exemplified in the case of the Temple of Serapis, described in the last chapter, and we might derive other illustrations from the events of the present century in South America.

Some writers, indeed, have imagined that there is geological evidence in Norway of the sudden upheaval of land to a considerable height at successive periods, since the era when the sea was inhabited by the living species of testacea. They point in proof to certain horizontal lines of inland cliffs and sea-beaches containing recent shells at various heights above the level of the sea.* But these appearances, when truly interpreted, simply prove that there have been long pauses in the process of upheaval or subsidence. They mark eras at which the level of the sea has remained stationary for ages, and during which new strata were deposited near the shore in some places, while in others the waves and currents had time to hollow out rocks,

* Keilhau, Bulletin de la Soc. Géol. de France, tom. vii. p. 18.

undermine cliffs, and throw up long ranges of shingle. They undoubtedly show that the movement has not been always uniform or continuous, but they do not establish the fact of any sudden alterations of level.

When we are once assured of the reality of the gradual rise of a large region, it enables us to account for many geological appearances otherwise very difficult of explanation. There are large continental tracts and high table lands where the strata are nearly horizontal, bearing no marks of having been thrown up by violent convulsions, nor by a series of movements, such as those which occur in the Andes, and cause the earth to be rent open, and raised or depressed from time to time, while large masses are engulphed in subterranean cavities. The result of a series of such earthquakes might be to produce in a great lapse of ages a country of shattered, inclined, and perhaps vertical strata. But a movement like that of Scandinavia would cause the bed of the sea, and all the strata recently formed in it, to be upheaved so gradually, that it would merely seem as if the ocean had formerly stood at a higher level, and had slowly and tranquilly sunk down into its present bed.

The fact also of a very gradual and insensible elevation of land may explain many geological monuments of denudation, on a grand scale. If, for example, instead of the hard granitic rocks of Norway and Sweden, a large part of the bed of the Atlantic, consisting chiefly of soft strata, should rise up, century after century, at the rate of about half an inch, or an inch, in a year, how easily might oceanic currents, such as those described in the seventh chapter, sweep away the thin film of matter thus brought up annually within the sphere of aqueous denudation! The tract,

when it finally emerged, might present table lands and ridges of horizontal strata, with intervening valleys and vast plains, where originally, and during its period of submergence, the surface was level and nearly uniform.

These speculations relate to superficial changes; but others must be continually in progress in the subterranean regions. The foundations of the country, thus gradually uplifted in Sweden, must be undergoing important modifications. Whether we ascribe these to the expansion of solid matter by continually increasing heat, or to the liquefaction of rock, or to the crystallization of a dense fluid, or the accumulation of pent-up gasses, in whatever conjectures we indulge, we can never doubt for a moment, that at some unknown depth beneath Sweden and the Baltic, the structure of the globe is in our own times becoming changed from day to day, throughout a space probably more than a thousand miles in length, and several hundred in breadth.

CHAPTER XIX.

CAUSES OF EARTHQUAKES AND VOLCANOS.

Intimate connexion between the causes of volcanos and earthquakes — Supposed original state of fusion of the planet — Universal fluidity not proved by spheroidal figure of the earth — Attempt to calculate the thickness of the solid crust of the earth by precessional motion — Heat in mines increasing with the depth — Objections to the supposed intense heat of a central fluid — Whether chemical changes may produce volcanic heat — Currents of electricity circulating in the earth's crust — Theory of an unoxidated metallic nucleus — The metallic oxides when heated may be deoxidated by hydrogen.

It will hardly be questioned, after the description before given of the phenomena of earthquakes and volcanos, that both of these agents have, to a certain extent, a common origin; and I may now, therefore, proceed to inquire into their probable causes. But first, it may be well to recapitulate some of those points of relation and analogy which lead naturally to the conclusion, that they spring from a common source.

The regions convulsed by violent earthquakes include within them the site of all the active volcanos. Earthquakes, sometimes local, sometimes extending over vast areas, often precede volcanic eruptions. The subterranean movement and the eruption return again and again, at irregular intervals of time, and with unequal degrees of force, to the same spots. The action

of either may continue for a few hours, or for several consecutive years. Paroxysmal convulsions are usually followed, in both cases, by long periods of tranquillity. Thermal and mineral springs are abundant in countries of earthquakes and active volcanos. Lastly, hot springs situated in districts considerably distant from volcanic vents have been observed to have their temperature suddenly raised, and the volume of their water augmented, by subterranean movements.

All these appearances are evidently more or less connected with the passage of heat from the interior of the earth to the surface; and where there are active volcanos, there must exist, at some unknown depth below, enormous masses of matter intensely heated, and, in many instances, in a constant state of fusion. We have first, then, to inquire, whence is this heat derived?

It has long been a favourite conjecture, that the whole of our planet was originally in a state of igneous fusion, and that the central parts still retain a great portion of their primitive heat. Some have imagined, with the late Sir W. Herschel, that the elementary matter of the earth may have been first in a gaseous state, resembling those nebulæ which we behold in the heavens, and which are of dimensions so vast, that some of them would fill the orbits of the remotest planets of our system. It is conjectured that such aëriform matter (for in many cases the nebulous appearance cannot be referred to clusters of very distant stars), if concentrated, might form solid spheres; and others have imagined that the evolution of heat, attendant on condensation, might retain the materials of the new globes in a state of igneous fusion.

Without dwelling on such speculations, which can

only have a distant bearing on geology, we may consider how far the spheroidal form of the earth affords sufficient ground for presuming that its primitive condition was one of universal fluidity. The discussion of this question would be superfluous, were the doctrine of original fluidity less popular; for it may well be asked, why the globe should be supposed to have had a pristine shape different from the present one? — why the terrestrial materials, when first called into existence, or assembled together in one place, should not have been subject to rotation, so as to assume at once that form which alone could retain their several parts in a state of equilibrium?

Let us, however, concede that the statical figure may be a modification of some other pre-existing form, and suppose the globe to have been at first a perfect and quiescent sphere, covered with a uniform ocean — what would happen when it was made to turn round on its axis with its present velocity? This problem has been considered by Playfair in his Illustrations, and he has decided, that if the surface of the earth, as laid down in Hutton's theory, has been repeatedly changed by the transportation of the detritus of the land to the bottom of the sea, the figure of the planet must in that case, whatever it may have been originally, be brought at length to coincide with the spheroid of equilibrium.* Sir John Herschel also, in reference to the same hypothesis, observes, " a centrifugal force would in that case be generated, whose general tendency would be to urge the water at every point of the surface to *recede* from the *axis*. A rotation might indeed be conceived so swift as to flirt the whole

* Illust. of Hutt. Theory, § 435—443.

ocean from the surface, like water from a mop. But this would require a far greater velocity than what we now speak of. In the case supposed, the *weight* of the water would still keep it *on* the earth; and the tendency to recede from the axis *could* only be satisfied therefore by the water leaving the poles, and flowing towards the equator; there heaping itself up in a ridge, and being retained in opposition to its weight or natural tendency towards the centre by the pressure thus caused. This, however, could not take place without laying dry the polar regions, so that protuberant land would appear at the poles, and a zone of ocean be disposed around the equator. This would be the first or immediate effect. Let us now see what would afterwards happen if things were allowed to take their natural course.

"The sea is constantly beating on the land, grinding it down, and scattering its worn-off particles and fragments, in the state of sand and pebbles, over its bed. Geological facts afford abundant proof that the existing continents have all of them undergone this process, even more than once, and been entirely torn in fragments, or reduced to powder, and submerged and reconstructed. Land, in this view of the subject, loses its attribute of fixity. As a mass it might hold together in opposition to forces which the water freely obeys; but in its state of successive or simultaneous degradation, when disseminated through the water, in the state of sand or mud, it is subject to all the impulses of that fluid. In the lapse of time, then, the protuberant land would be destroyed, and spread over the bottom of the ocean, filling up the lower parts, and tending continually to re-model the surface of the solid nucleus, in correspondence with the *form of equi-*

librium. Thus after a sufficient lapse of time, in the case of an earth in rotation the polar protuberances would gradually be cut down and disappear, being transferred to the equator (as being *then* the *deepest sea*), till the earth would assume by degrees the form we observe it to have — that of a flattened or *oblate* ellipsoid.

"We are far from meaning here to trace the process *by which* the earth really assumed its actual form; all we intend is to show that this is the form to which, under a condition of a rotation on its axis, it must *tend*, and which it would attain even if originally and (so to speak) perversely constituted otherwise." *

In this passage, the author has contemplated the superficial effects of aqueous causes only; but neither he nor Playfair seem to have followed out the same inquiry with reference to another part of Hutton's system; namely, that which assumes the successive fusion by heat of different parts of the solid earth. Yet the progress of geology has continually strengthened the evidence in favor of the doctrine that local variations of temperature have melted one part after another of the earth's crust, and this influence has perhaps extended downwards to the very centre. If, therefore, before the globe had assumed its present form, it was made to revolve on its axis, all matter to which freedom of motion was given by fusion must before consolidating have been impelled towards the equatorial regions in obedience to the centrifugal force. Thus lava flowing out in superficial streams would have its motion retarded when its direction was towards the pole, accelerated when towards the equator, or if lakes and seas

* Herschel's Astronomy, chap. iii.

of lava existed beneath the earth's crust in equatorial regions, as probably now beneath the Peruvian Andes, the imprisoned fluid would force outwards and permanently upheave the overlying rocks. The statical figure, therefore, of the terrestrial spheroid (of which the longest diameter exceeds the shortest by about twenty-five miles), may have been the result of gradual and even of existing causes, and not of a primitive, universal, and simultaneous fluidity.

Experiments made with the pendulum, and observations on the manner in which the earth attracts the moon, have shown that our planet is not an empty sphere, but, on the contrary, that its interior, whether solid or fluid, has a higher specific gravity than the exterior. It has also been inferred, that there is a regular increase in density from the surface towards the centre, and that the equatorial protuberance is continued inwards; that is to say, that layers of equal density are arranged elliptically, and symmetrically, from the exterior to the centre. These conclusions, however, have been deduced rather as a consequence of the hypothesis of primitive and simultaneous fluidity than proved by experiment. The inequalities in the moon's motion, by which some have endeavoured to confirm them, are so extremely slight, that the opinion can be regarded as little more than a probable conjecture.

The mean density of the earth has been computed by Laplace to be about 5½, or more than five times that of water. Now the specific gravity of many of our rocks is from 2½ to 3, and the greater part of the metals range between that density and 21. Hence some have imagined that the terrestrial nucleus may be metallic — that it may correspond, for example,

with the specific gravity of iron, which is about 7. But here a curious question arises in regard to the form which materials, whether fluid or solid, might assume, if subjected to the enormous pressure which must obtain at the earth's centre. Water, if it continued to decrease in volume according to the rate of compressibility deduced from experiment, would have its density doubled at the depth of ninety-three miles, and be as heavy as mercury at the depth of 362 miles. Dr. Young computed that, at the earth's centre, steel would be compressed into one fourth, and stone into one eighth of its bulk.* It is more than probable, however, that after a certain degree of condensation, the compressibility of bodies may be governed by laws altogether different from those which we can put to the test of experiment; but the limit is still undetermined, and the subject is involved in such obscurity, that we cannot wonder at the variety of notions which have been entertained respecting the nature and conditions of the central nucleus. Some have conceived it to be fluid, others solid; some have imagined it to have a cavernous structure, and have even endeavoured to confirm this opinion by appealing to observed irregularities in the vibrations of the pendulum in certain countries.

An attempt has recently been made by Mr. Hopkins to determine the least thickness which can be assigned to the solid crust of the globe, if we assume the whole to have been once perfectly fluid, and a certain portion of the exterior to have acquired solidity by gradual refrigeration. This result he has endeavoured to obtain by a new solution of the delicate problem of the

* Young's Lectures, and Mrs. Somerville's Connexion of the Physical Sciences, p. 90.

precessional motion of the pole of the earth. It is well known that while the earth revolves round the sun the direction of its axis remains very nearly the same, i. e. its different positions in space are all nearly parallel to each other. This parallelism, however, is not accurately preserved, so that the axis, instead of coming exactly into the position which it occupied a year before, becomes inclined to it at a very small angle, but always retaining very nearly the same inclination to the plane of the earth's orbit. This motion of the pole changes the position of the equinoxes by about fifty seconds annually, and always in the same direction. Thus the pole-star, after a certain time, will entirely lose its claim to that appellation, until in the course of somewhat more than 25,000 years the earth's axis shall again occupy its present angular position, and again point very nearly as now to the pole-star. This motion of the axis is called *precession*. It is caused by the attraction of the sun and moon on the protuberant parts at the earth's equator, and if these parts were solid to a great depth, the motion thus produced would differ considerably from that which would exist if they were perfectly fluid, and incrusted over with a thin shell only a few miles thick. Mr. Hopkins has, therefore, calculated the amount of precessional motion which would result if we assume the earth to be constituted as above stated; i. e. fluid internally, and enveloped by a solid shell; and he finds that the amount will not agree with the observed motion, unless the crust of the earth be of a certain thickness. In calculating the exact amount some ambiguity arises in consequence of our ignorance of the effect of pressure in promoting the solidification of matter at high temperatures. The hypothesis least favourable for a great

thickness is found to be that which assumes the pressure to produce no effect on the process of solidification. Even on this extreme assumption the thickness of the solid crust must be nearly *four hundred miles*, and if the solidifying influence of pressure be considerable, it will probably require a shell of 800 miles to enable us to explain the observed amount of precession.*

At the same time it should be remarked, that any still *greater* thickness would be quite consistent with the actual phenomena; and these calculations are not opposed to the supposition of the general solidity of the entire globe. Nor do they preclude us from imagining that great lakes or seas of melted matter may be distributed through a shell 400 or 800 miles thick, provided they be so inclosed as to move with it, whatever motion of rotation may be communicated by the disturbing forces of the sun and moon.

Central Heat.— The hypothesis of internal fluidity calls for the more attentive consideration, as it has been found that the heat in mines augments in proportion as we descend. Observations have been made, not only on the temperature of the air in mines, but on that of the rocks, and on the water issuing from them. The mean rate of increase, calculated from results obtained in six of the deepest coal mines in Durham and Northumberland, is 1° Fahr. for a descent of forty-four English feet.† A series of observations, made in several of the principal lead and silver mines in Saxony, gave 1° Fahr. for every sixty-five feet. In this case, the bulb of the thermometer was introduced into cavities purposely cut in the solid rock at depths varying from two hundred to above nine hundred feet.

* Phil. Trans. 1839. † Ed. Journal of Sci. April, 1832.

But in other mines of the same country, it was necessary to descend thrice as far for each degree of temperature.*

A thermometer was fixed in the rock of the Dolcoath mine, in Cornwall, by Mr. Fox, at the great depth of 1380 feet, and frequently observed during eighteen months; the mean temperature was 68° Fahr., that of the surface being 50°, which gives 1° for every seventy-five feet.

Kupffer, after an extensive comparison of the results in different countries, makes the increase 1° F. for about every thirty-seven English feet.† M. Cordier announces, as the result of his experiments and observations on the temperature of the interior of the earth, that the heat increases rapidly with the depth; but the increase does not follow the same law over the whole earth, being twice or three times as much in one country as in another, and these differences are not in constant relation either with the latitudes or longitudes of places.‡ He is of opinion, however, that the increase would not be overstated at 1° Cent. for every twenty-five metres, or about 1° F. for every forty-five feet.§ The experimental well now boring at Grenelle near Paris gave about 1° F. for every sixty English feet when they reached a depth of 1312 feet.

Some writers have endeavoured to refer these phenomena (which, however discordant as to the ratio of increasing heat, appear all to point one way) to the

* Cordier, Mém. de l'Instit. tom. vii.

† Pog. Ann. tom. xv. p. 159.

‡ See M. Cordier's Memoir on the Temperature of the Interior of the Earth, read to the Academy of Sciences, 4th June, 1827. — Edin. New Phil. Journal, No. viii. p. 273.

§ Cordier, Mém. de l'Instit. tom. vii.

condensation of air constantly descending from the surface into the mines. For the air under pressure would give out latent heat, on the same principle as it becomes colder when rarified in the higher regions of the atmosphere. But, besides that the quantity of heat is greater than could be supposed to flow from this source, the argument has been answered in a satisfactory manner by Mr. Fox, who has shown, that in the mines of Cornwall the ascending have generally a higher temperature than the descending aërial currents. The difference between them was found to vary from 9° to 17° F.: a proof, that instead of imparting heat, these currents actually carry off a large quantity from the mines.*

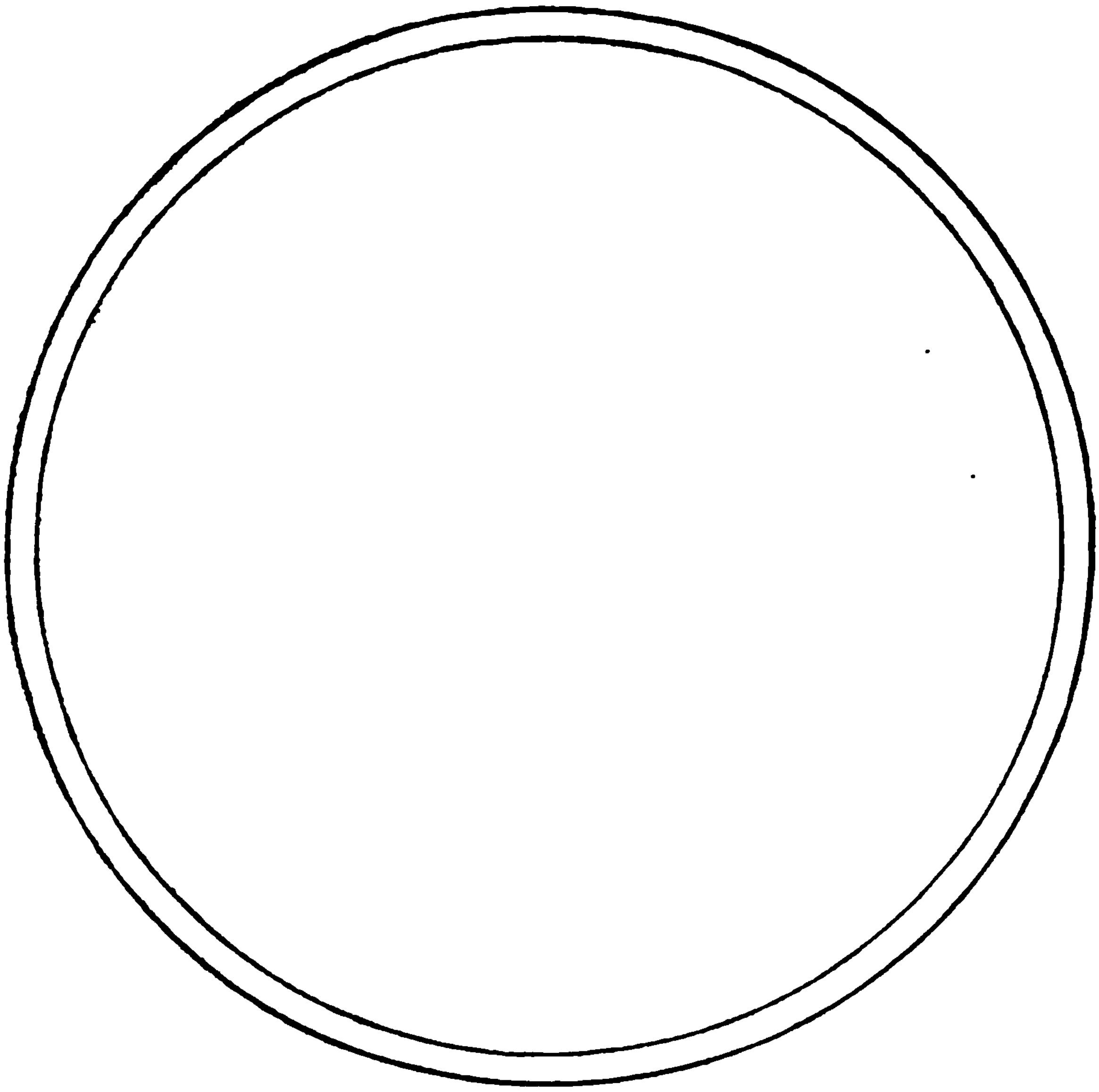
If we adopt M. Cordier's estimate of 1° F. for every 45 feet of depth as the mean result, and assume, with the advocates of central fluidity, that the increasing temperature is continued downwards, we should reach the ordinary boiling point of water at about two miles below the surface, and at the depth of about twenty-four miles should arrive at the melting point of iron, a heat sufficient to fuse almost every known substance. The temperature of melted iron was estimated at 21,000° F., by Wedgwood; but his pyrometer gives, as is now demonstrated, very erroneous results. It has been ascertained by Professor Daniell, that the point of fusion is 2786° F.†

* Phil. Mag. and Ann. Feb. 1830.

† The heat was measured in Wedgwood's pyrometer by the contraction of pure clay, which is reduced in volume when heated, first by the loss of its water of combination, and afterwards on the application of more intense heat, by incipient vitrification. The expansion of platina is the test employed by Mr. Daniell, in his pyrometer, and this has been found to yield uniform and con-

According to Mr. Daniell's scale, we ought to encounter the internal melted matter before penetrating through a thickness represented by that of the outer circular line in the annexed diagram (Fig. 70.);

Fig. 70.



Section of the earth in which the breadth of the outer boundary line represents a thickness of 25 miles; the space between the circles including the breadth of the lines, 200 miles.

whereas, if the other or less correct scale be adopted, we should meet with it at some point between the two

sistent results, such as are in perfect harmony with conclusions drawn from various other independent sources. The instrument for which the author received the Rumford Medal from the Royal Society in 1833, is described in the Phil. Trans. 1830, part ii., and 1831, part ii.

circles; the space between them, together with the lines themselves, representing a crust of two hundred miles in depth. In either case, we must be prepared to maintain, that a temperature many times greater than that sufficient to melt the most refractory substances known to us, is sustained at the centre of the globe; while a comparatively thin crust, resting upon the fluid, remains unmelted; or is even, according to M. Cordier, increasing in thickness, by the continual addition of new internal layers solidified during the process of refrigeration.

The mathematical calculations of Fourier, on the passage of heat through conducting bodies, have been since appealed to in support of these views; for he has shown that it is compatible with theory that the present temperature of the surface might co-exist with an intense heat, at a certain depth below. But his reasoning seems to be confined to the conduction of heat through solid bodies; and the conditions of the problem are wholly altered when we reason about a fluid nucleus, as we must do, if it be assumed that the heat augments from the surface to the interior, according to the rate observed in mines. For when the heat of the lower portion of a fluid is increased, a circulation begins throughout the mass, by the ascent of hotter, and the descent of colder currents. And this circulation, which is quite distinct from the mode in which heat is propagated through solid bodies, must evidently occur in the supposed central ocean, if the laws of fluids and of heat are the same there as upon the surface.

In Mr. Daniell's recent experiments for obtaining a measure of the heat of bodies, at their point of fusion, he invariably found that it was impossible to raise the

heat of a large crucible of melted iron, gold, or silver, a single degree beyond the melting point, so long as a bar of the respective metals was kept immersed in the fluid portions. So in regard to other substances, however great the quantities fused, their temperature could not be raised while any solid pieces immersed in them remained unmelted; every accession of heat being instantly absorbed during their liquefaction. These results are, in fact, no more than the extension of a principle previously established, that so long as a fragment of ice remains in water, we cannot raise the temperature of the water above 32° F.

If, then, the heat of the earth's centre amount to 450,000° F., as M. Cordier deems highly probable, that is to say, about twenty times the heat of melted iron, even according to Wedgwood's scale, and upwards of 160 times according to the improved pyrometer, it is clear that the upper parts of the fluid mass could not long have a temperature only just sufficient to melt rocks. There must be a continual tendency towards a uniform heat; and until this were accomplished, by the interchange of portions of fluid of different densities, the surface could not begin to consolidate. Nor, on the hypothesis of primitive fluidity, can we conceive any crust to have been formed until *the whole* planet had cooled down to about the temperature of incipient fusion.

It cannot be objected that hydrostatic pressure would prevent a tendency to equalization of temperature; for, as far as observations have yet been made, it is found that the waters of deep lakes and seas are governed by the same laws as a shallow pool; and no experiments indicate that solids resist fusion under high pressure. The arguments, indeed, now con-

troverted, always proceed on the admission that the internal nucleus is in a state of fusion.

It may be said that we may stand upon the hardened surface of a lava current while it is still in motion, — nay, may descend into the crater of Vesuvius after an eruption, and stand on the scoriæ while every crevice shows that the rock is red-hot two or three feet below us; and at a somewhat greater depth, all is, perhaps, in a state of fusion. May not, then, a much more intense heat be expected at the depth of several hundred yards, or miles? The answer is, — that, until a great quantity of heat has been given off, either by the emission of lava, or in a latent form by the evolution of steam and gas, the melted matter continues to boil in the crater of a volcano. But ebullition ceases when there is no longer a sufficient supply of heat from below, and then a crust of lava may form on the top, and showers of scoriæ may then descend upon the surface, and remain unmelted. If the internal heat be raised again, ebullition will recommence, and soon fuse the superficial crust. So in the case of the moving current, we may safely assume that no part of the liquid beneath the hardened surface is much above the temperature sufficient to retain it in a state of fluidity.

It may assist us in forming a clearer view of the doctrine now controverted, if we consider what would happen were a globe of homogeneous composition placed under circumstances analogous, in regard to the distribution of heat, to those above stated. If the whole planet, for example, were composed of water covered with a spheroidal crust of ice fifty miles thick, and with an interior ocean having a central heat about two hundred times that of the melting point of ice, or

6400° F.; and if, between the surface and the centre, there was every intermediate degree of temperature between that of melting ice and that of the central nucleus; — could such a state of things last for a moment? If it must be conceded, in this case, that the whole spheroid would be instantly in a state of violent ebullition, that the ice (instead of being strengthened annually by new internal layers, would soon melt, and form part of an atmosphere of steam — on what principle can it be maintained that analogous effects would not follow, in regard to the earth, under the conditions assumed in the theory of central heat? *

M. Cordier admits that there must be tides in the internal melted ocean; but their effect, he says, has become feeble, although originally, when the fluidity of the globe was perfect, "the rise and fall of these ancient land tides could not have been less than from thirteen to sixteen feet." Now granting, for a moment, that these tides have become so feeble as to be incapable of causing the fissured shell of the earth to be first uplifted and then depressed every six hours, still may we not ask whether, during eruptions, the lava, which is supposed to communicate with a great central ocean,

* The above remarks are reprinted verbatim from my third edition, May 1834. A memoir was afterwards communicated by M. Poisson to the Academy of Sciences, January, 1837, on the solid parts of the globe, containing an epitome of a work entitled "Théorie Mathématique de la Chaleur," published in 1835. In this memoir he controverts the doctrine of the high temperature of a central fluid on similar grounds to those above stated. He imagines, that if the globe ever passed from a liquid to a solid state by radiation of heat, the central nucleus must have begun to cool and consolidate first.

would not rise and fall sensibly in a crater such as Stromboli, where there is always melted matter in a state of ebullition?

Whether chemical changes may produce volcanic heat. — Having now explained the reasons which have induced me to question the hypothesis of central heat as the primary source of volcanic action, it remains to consider what has been termed the chemical theory of volcanos. It is well known that many, perhaps all, of the substances of which the earth is composed are continually undergoing chemical changes. To what depth these processes may be continued downwards must, in a great degree, be matter of conjecture; but there is no reason to suspect that, if we could descend to a great distance from the surface, we should find elementary substances differing essentially from those with which we are acquainted.

Playfair has, indeed, attempted to deduce, from an observation of Pallas, that we can, by the aid of geology, see, as it were, into the interior as far as thirty miles or more; for Pallas had described, in the peninsula of Tauris, a series of parallel strata as regular as the leaves of a book, inclined at an angle of 45° to the horizon, and exposed in a continuous section eighty-six English miles long. The height of the range of hills composed of these strata does not exceed twelve hundred feet; but if we measure the thickness of the stratified mass by a line perpendicular to its stratification, the height of the uppermost bed above the undermost must have been originally more than sixty miles; and even allowing, says Playfair, that the strata had shifted during their elevation, we may still suppose a thickness of thirty miles. But, if a deception to the extent of one half is allowed for, on the score of shift-

ing, it may well be asked why the same cause might not have produced a much greater amount of error? It is, moreover, an established doctrine with geologists that strata have, in many situations, accumulated originally on an inclined plane, as must now take place wherever sand, mud, and gravel are thrown into deep water by rivers and torrents. When the beds have been deposited in this manner on a slope they may easily be mistaken for horizontal strata which have been tilted by subsequent movements, and in that case a very exaggerated estimate would be formed of the vertical depth of the original deposit.

Nevertheless, since we discover in mountain chains strata thousands of feet thick, which must have been formed at the bottom of the sea, but are now raised to the height of three or four miles above it, we may fairly speculate on the probability of rocks, such as are now on the surface, existing at the depth of several leagues below.

We may next recall to mind that all the solid, fluid, and gaseous bodies which enter into the composition of the earth, consist of a very small number of elementary substances variously combined: the total number of elements at present known is less than sixty; and not half of these enter into the composition of the more abundant inorganic productions.

Some portions of the compounds above alluded to are daily resolved into their elements; and these, on being set free, are always passing into new combinations. These processes are by no means confined to the surface, and are almost always accompanied by the evolution of heat, which is intense in proportion to the rapidity of the combinations. At the same time, there is a development of electricity.

It is well known that mixtures of sulphur and iron, sunk in the ground, and exposed to moisture, give out sufficient heat to pass gradually into a state of combustion, and to set fire to any bodies that are near. The following experiment was first made by Lemery: Let a large quantity of clean iron filings be mixed with a still larger proportion of sulphur, and as much water as is necessary to make them into a firm paste. Let the mixture be then buried in the earth, and the soil pressed down firmly upon it. In a few hours it will grow warm, and swell so as to raise the ground; sulphureous vapours will make their way through the crevices, and sometimes flames appear. There is rarely an explosion; but, when this happens, the fire is vivid, and, if the quantity of materials is considerable, the heat and fire both continue for a long time.*

The spontaneous combustion of beds of bituminous shale, and of refuse coal thrown out of mines, is also generally due to the decomposition of pyrites; and it is the contact of water, not of air, which brings about the change. A smouldering heat results from the various new combinations, which immediately take place when the sulphur and other substances are set free. Similar effects are often produced in mines where no coaly matter is present, where substances capable of being decomposed by water are heaped together.

On what principle heat is generated, when two or more bodies having a strong affinity for each other unite suddenly, is wholly unexplained; but it is a singular fact that, while chemical combination causes heat, the disunion of elements does not produce the opposite effect, or a corresponding degree of cold. It

* Daubney's Volcanos, p. 356.

may be said that decomposition is usually brought about by the combination of one or more of the elements with a new substance, and this concomitant agency might be supposed to neutralize or counterbalance any frigorific effects which might otherwise be sensible. But this explanation is, in many cases, wholly inapplicable; as, for example, when the voltaic pile is used for decomposition, or in the more striking instance of the well-known detonating powder, the iodide of nitrogen, which explodes with violence in the open air, the instant it is touched by a cold substance. The two elements into which this binary compound is resolved fly off in a gaseous form, and do not unite with any other body, the iodine rising in a purple vapour, while the nitrogen may be collected separately. Yet sudden as is the process by which their union is broken, we find that heat and light, instead of cold, are generated.

Electricity a source of volcanic heat. — It has already been stated, that chemical changes develop electricity; which, in its turn, becomes a powerful disturbing cause. As a chemical agent, says Davy, its silent and slow operation in the economy of nature is much more important than its grand and impressive operation in lightning and thunder. It may be considered, not only as directly producing an infinite variety of changes, but as influencing almost all which take place; it would seem, indeed, that chemical attraction itself is only a peculiar form of the exhibition of electrical attraction.*

Now that it has been demonstrated that magnetism and electricity are always associated, and are perhaps

* Consolations in Travel, p. 271.

only different conditions of the same power, the phenomena of terrestrial magnetism have become of no ordinary interest to the geologist. Soon after the first great discoveries of Oersted in electro-magnetism, Ampere suggested that all the phenomena of the magnetic needle might be explained by supposing currents of electricity to circulate constantly in the shell of the globe in directions parallel to the magnetic equator. This theory has acquired additional consistency the farther we have advanced in science; and according to the experiments of Mr. Fox, on the electro-magnetic properties of metalliferous veins, some trace of electric currents seems to have been detected in the interior of the earth.*

Some philosophers ascribe these currents to the chemical action going on in the superficial parts of the globe to which air and water have the readiest access; while others refer them, in part at least, to thermo-electricity excited by the solar rays on the surface of the earth during its rotation; successive parts of the land and sea being exposed to the influence of the sun, and then cooled again in the night. That this idea is not a mere speculation, is proved by the correspondence of the diurnal variations of the magnet with the apparent motion of the sun; and by the greater amount of variation in summer than in winter, and during the day than in the night. M. de la Rive, although conceding that such minor variations of the needle may be due to thermo-electricity, contends that the general phenomena of terrestrial magnetism must be attributed to currents far more intense; which, though liable to secular fluctuations, act with

* Phil. Trans. 1830, p. 399.

much greater constancy and regularity than the causes which produce the diurnal variations.* The remark seems just; yet it is difficult to assign limits to the accumulated influence even of a very feeble force constantly acting on the whole surface of the earth. This subject, however, must evidently remain obscure, until we become acquainted with the causes which give a determinate direction to the supposed electric currents. Already the experiments of Faraday on the rotation of magnets have led him to speculate on the manner in which the earth, when once it had become magnetic, might produce electric currents within itself, in consequence of its diurnal rotation.†

Before leaving the consideration of thermo-electricity, I may remark, that it may be generated by great inequalities of temperature, arising from a partial distribution of volcanic heat. Wherever, for example, masses of rock occur of great horizontal extent, and of considerable depth, which are at one point in a state of fusion (as beneath some active volcano); at another, red hot; and at a third, comparatively cold — strong thermo-electric action may be excited.

Some, perhaps, may object, that this is reasoning in a circle; first to introduce electricity as one of the primary causes of volcanic heat, and then to derive the same heat from thermo-electric currents. But there must, in truth, be much reciprocal action between the agents now under consideration; and it is very difficult to decide which should be regarded as the prime mover, or to see where the train of changes, once begun, would terminate.

* Biblioth. Univers., 1833, Electricité.

† Phil. Trans., 1832, p. 176.; also pp. 172, 173, &c.

In the ordinary operations of nature, it is in the atmosphere alone that we observe the action of electricity; and it is probable that a moment never passes without a flash of lightning striking some part of the earth. The electric fluid shatters rocks, and instantaneously melts substances which are commonly regarded as infusible. The air is supposed to derive a great part of this electricity directly from the earth;* and M. Necker seems to have succeeded in establishing that there is a connection between the direction of the curves of equal magnetic intensity and the *strike* of the principal mountain chains.† Some, also, attribute the electricity of the air to the evaporation of sea-water by the sun: for it can be shown, by experiment, that the conversion of salt water into vapour is accompanied by the excitement of electricity; and the process alluded to takes place on so vast a scale,— the measure of the quantity of evaporation being the constant flow of all the rivers of the earth exclusive of the rain which falls directly into the ocean,—that a feeble action of this kind may become very powerful by accumulation.

During volcanic eruptions, vivid lightnings are almost invariably seen in the clouds of vapour which ascend from the crater; and, as there are always one or more eruptions going on in some part of the globe, we are here presented with another perpetual source of derangement. How far subterranean electric currents may possess the decomposing power of the voltaic pile is a question for those alone who are farthest advanced in the career of discovery in a rapidly pro-

* Faraday, Phil. Trans., 1832, p. 177.

† Biblioth, Univers., tom. xliii. p. 166.

gressive science; but such a power would at once supply us with a never-failing source of chemical action, from which volcanic heat might be derived.

Recapitulation. — In the next chapter I shall enter still further into the inquiry, how far the phenomena of volcanos and earthquakes accord with the hypothesis of a continued generation of heat by chemical action. But, first, it may be desirable to recapitulate, in a few words, the conclusions already obtained.

1st. The primary causes of the volcano and the earthquake are, to a great extent, the same, and must be connected with the passage of heat from the interior to the surface.

2dly. This heat has been referred, by many, to a supposed state of igneous fusion of the central parts of the planet when it was first created, of which a part still remains in the interior, but is always diminishing in intensity.

3dly. The spheroidal figure of the earth, adduced in support of this theory, does not of necessity imply a universal and simultaneous fluidity, in the beginning; for supposing the original figure of our planet had been strictly spherical — which, however, is a gratuitous assumption, resting on no established analogy — still the statical figure must have been assumed, if sufficient time be allowed, by the gradual operation of the centrifugal force, acting on the materials brought successively within its action by aqueous and igneous causes.

4thly. It appears, from experiment, that the heat in mines increases progressively with their depth; and if the ratio of increase be continued uniformly from the surface to the interior, the whole globe, with the exception of a small external shell, must be fluid, and

the central parts must have a temperature many times higher than that of melted iron.

5thly. But the theory adopted by M. Cordier and others, which maintains the actual existence of such a state of things, seems wholly inconsistent with the laws which regulate the circulation of heat through fluid bodies. For, if the central heat were as intense as is represented, there must be a circulation of currents, tending to equalize the temperature of the resulting fluids, and the solid crust itself would be melted.

6thly. Instead of an original central heat, we may, perhaps, refer the heat of the interior to chemical changes constantly going on in the earth's crust; for the general effect of chemical combination is the evolution of heat and electricity, which, in their turn, become sources of new chemical changes.

7thly. The existence of currents of electricity in the shell of the earth has been deduced from the phenomena of terrestrial magnetism; from the connection between the diurnal variations of the magnet and the apparent motion of the sun; from observations on the electro-magnetic properties of metalliferous veins; and, lastly, from atmospheric electricity, which is continually passing between the air and the earth.

8thly. Subterranean electric currents may exert a slow decomposing power like that of the voltaic pile, and thus become a constant source of chemical action, and, consequently, of volcanic heat.

CHAPTER XX.

CAUSES OF EARTHQUAKES AND VOLCANOS — *continued.*

Review of the proofs of internal heat — Theory of an unoxidated metallic nucleus — Decomposition of water a source of volcanic heat — Geysers of Iceland — Causes of earthquakes — Wave-like motion — Expansive power of liquid gases — Connexion between the state of the atmosphere and earthquakes — Permanent upheaval and subsidence of land — Expansion of rocks by heat — The balance of dry land how preserved — Subsidence in excess — Conclusion.

When we reflect that the largest mountains are but insignificant protuberances upon the surface of the earth, and that these mountains are nevertheless composed of different parts which have been formed in succession, we may well feel surprise that the central fluidity of the planet should have been called in to account for volcanic phenomena. To suppose the entire globe to be in a state of igneous fusion, with the exception of a solid shell, not more than from thirty to one hundred miles thick, and to imagine that the central heat of this fluid spheroid exceeds by more than two hundred times that of liquid lava, is to introduce a force altogether disproportionate to the effects which it is required to explain.

The ordinary repose of the surface implies, on the contrary, an inertness in the internal mass which is

truly wonderful. When we consider the combustible nature of the elements of the earth, so far as they are known to us,—the facility with which their compounds may be decomposed, and made to enter into new combinations,—the quantity of heat which they evolve during these processes; when we recollect the expansive power of steam, and that water itself is composed of two gases which, by their union, produce intense heat; when we call to mind the number of explosive and detonating compounds which have been already discovered, we may be allowed to share the astonishment of Pliny, that a single day should pass without a general conflagration:—"Excedit profectò omnia miracula, ullum diem fuisse quo non cuncta conflagrarent."*

The signs of internal heat observable on the surface of the earth do not necessarily indicate the permanent existence of subterranean heated masses, whether fluid or solid, by any means so vast as our continents and seas; yet how insignificant would these appear if distributed through an external shell of the globe one or two hundred miles in depth! The principal facts in proof of the accumulation of heat below the surface may be summed up in a few words. Several volcanos are constantly in eruption, as Stromboli and Nicaragua; others are known to have been active for periods of 60, or even 150 years, as those of Sangay in Quito, Popocatepetl in Mexico, and the volcano of the Isle of Bourbon. Many craters emit hot vapours in the intervals between eruptions, and solfataras evolve incessantly the same gases as volcanos. Steam of high temperature has continued for more than twenty cen-

* Hist. Mundi, lib. ii. c. 107.

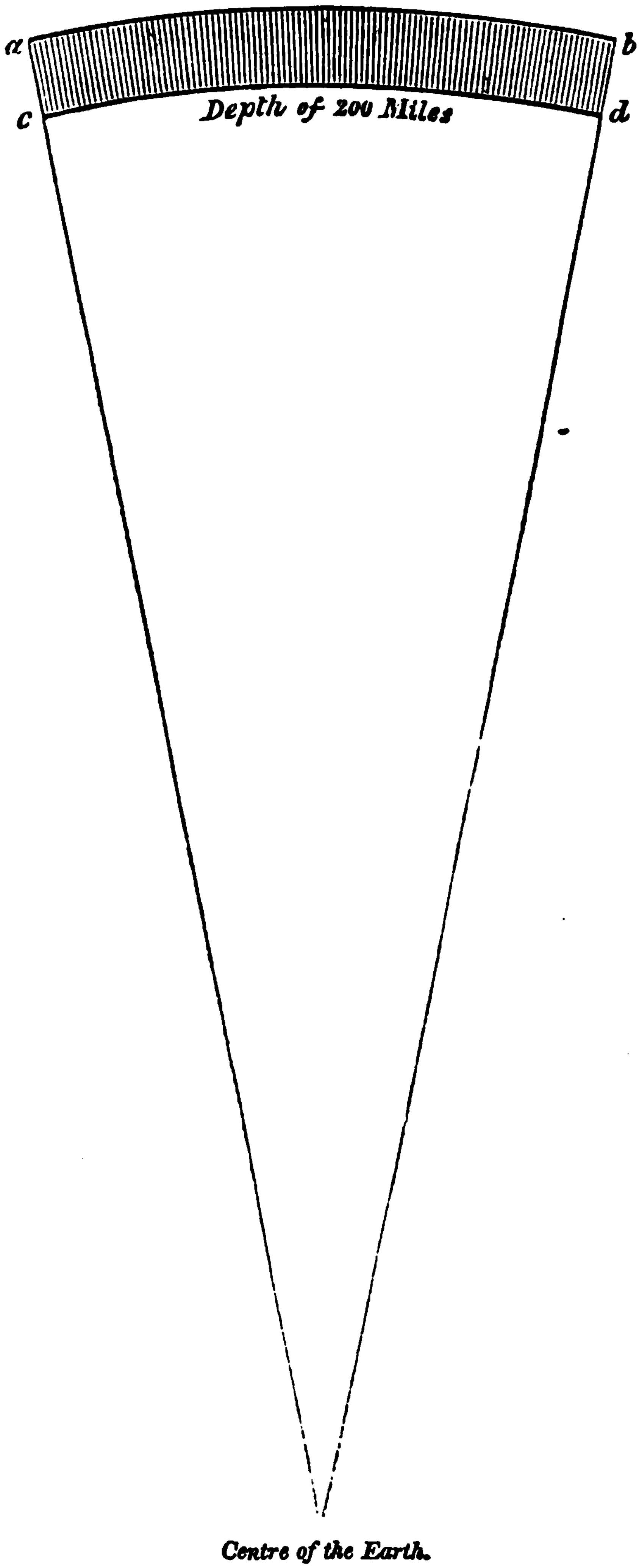
turies to issue from the "stufas," as the Italians call them,— thermal springs abound not only in regions of earthquakes, but are found in almost all countries, however distant from active vents; and, lastly, the temperature in the mines of various parts of the world is found to increase in proportion as we descend.

It is probably to this unceasing discharge of subterranean heat that we owe the general tranquillity of the globe; and the occasional convulsions which occur may arise from the temporary stoppage of the channels by which heat is transmitted to the surface; for the passage of caloric from below upwards may be compared to the descent of water from the continents to the sea; and as a partial interruption of the drainage of a country causes a flood, so any obstruction to the discharge of volcanic heat may give rise to an earthquake or eruption.

The annexed diagram (fig. 71.) may convey some idea of the proportion which our continents and the ocean bear to the radius of the earth.* If all the land were about as high as the Himalaya mountains, and the ocean every where as deep as the Pacific, the whole of both might be contained within a space expressed by the thickness of the line *a b;* and masses of nearly equal volume might be placed in the space marked by the line *c d*, in the interior. Seas of lava, therefore, of the size of the Mediterranean, or even of the Atlantic, would be as nothing if distributed through such an outer shell of the globe as is represented by the shaded portion of the figure *a b c d.* If throughout that space we imagine electro-chemical

* Reduced, by permission, from a figure in plate 40. of Mr. De la Beche's Geological Sections and Views.

Fig. 71.



causes to be continually in operation, even of very feeble power, they might give rise to heat which, if accumulated at certain points, might melt or render red-hot entire mountains, or sustain the temperature of stufas and hot springs for ages.

Theory of an unoxidated metallic nucleus.— When Sir H. Davy first discovered the metallic bases of the earths and alkalies, he threw out the idea that those metals might abound in an unoxidized state in the subterranean regions to which water must occasionally penetrate. Whenever this happened, gaseous matter would be set free, the metals would combine with the oxygen of the water, and sufficient heat might be evolved to melt the surrounding rocks. This hypothesis was at first very favourably received both by the chemist and the geologist; for silica, alumina, lime, soda, and oxide of iron,— substances of which lavas are principally composed,— would all result from the contact of the inflammable metals alluded to with water. But whence this abundant store of unsaturated metals in the interior? It was assumed that, in the beginning of things, the nucleus of the earth was mainly composed of inflammable metals, and that oxidation went on with intense energy at first; till, at length, when a superficial crust of oxides had been formed, the chemical action became more and more languid.

If we indulge in this speculation, which, like all others respecting the primitive state of the earth's nucleus is arbitrary, we are naturally led to inquire whether any existing causes may have the power of deoxidating the earthy and alkaline compounds formed from time to time by the action of water upon the metallic bases. If so the previous state of the metallic

bases might be restored, a permanent chemical action sustained, and a continual circle of operation kept up. It has been suggested to me, by Mr. Daniell, that we have, in hydrogen, precisely such a deoxidating agent as would be required. It is well known to chemists, that the metallization of oxides, the most difficult to reduce, may be effected by hydrogen brought into contact with them at a red heat; and it is more than probable that the production of potassium itself, in the common gun-barrel process, is due to the power of nascent hydrogen derived from the water which the hydrated oxide contains. According to the recent experiments, also, of Faraday, it would appear that every case of metallic reduction by voltaic agency, from saline solutions, in which water is present, is due to the secondary action of hydrogen upon the oxide; both of these being determined to the negative pole and then re-acting upon one another.

It has never been disputed that intense heat might be produced by the occasional contact of water with the metallic bases; and it is quite certain that, during the process of saturation, vast volumes of hydrogen must be evolved. The hydrogen, thus generated, might permeate the crust of the earth in different directions, and be stored up for ages in fissures and caverns, sometimes in a liquid form, under the necessary pressure. Whenever, at any subsequent period, in consequence of the changes effected by earthquakes in the shell of the earth, this gas happened to come in contact with metallic oxides at a high temperature, the reduction of these oxides would be the necessary result.

No theory seems at first more improbable, than that which represents water as affording an inexhaustible

supply of fuel to the volcanic fires; yet the hypothesis is far from visionary; and it is a fact that must never be overlooked, that while a great number of volcanos are entirely submarine, the remainder are for the most part in islands or maritime tracts. There are a few exceptions, but some of these, as Dr. Daubeny observes, are near inland salt lakes, as in Central Tartary; while others form part of a train of volcanos, the extremities of which are near the sea. Thus Jorullo, in Mexico, though itself not less than forty leagues from the nearest ocean, appears to be connected with the volcano of Tuxtla on the one hand, and that of Colima on the other; the first bordering on the Atlantic, the latter on the Pacific Ocean. This communication is rendered more probable by the parallelism that exists between these and several intermediate volcanic hills.*

Sir H. Davy supposes that, when the sea is distant, as in the case of some of the South American volcanos, they may still be supplied with water from subterranean lakes; since, according to Humboldt, large quantities of fish are often thrown out during eruptions.†

When treating of springs and overflowing wells, I have stated that porous rocks are percolated by fresh water to great depths, and that sea-water probably penetrates in the same manner through the rocks which form the bed of the ocean. But, besides this universal circulation in regions not far from the surface, it must be supposed that, wherever earthquakes prevail, much larger bodies of water will be forced by the pressure

* See Daubeny's remarks—"Volcanos," p. 368.

† Phil. Trans. 1828, p. 250.

of the ocean into fissures at greater depths, or swallowed up in chasms; in the same manner as, on the land, towns, houses, cattle, and trees are sometimes engulphed. It will be remembered, that these chasms often close again after houses have fallen into them; and for the same reason, when water has penetrated to a mass of melted lava, the steam into which it is converted may often rush out at a different aperture from that by which the water entered. The frequent explosions caused by the generation of steam in the neighbourhood of the sea or of deep lakes, may shatter the solid crust of the earth, and allow the free escape of gasses and lava which, but for this cause, might never have reached the surface, and might only have given rise to earthquakes.

It seems generally admitted, that the gasses exhaled from volcanos, together with steam, are such as would result from the decomposition of salt water, and the fumes which escape from the Vesuvian lava have been observed to deposit common salt.* The emission of free muriatic acid gas in great quantities favours the theory of the decomposition of the salt contained in sea water. It has been objected, however, that M. Boussingault did not meet with this gas in his late examination of the elastic fluids evolved from the volcanos of equatorial America; which only give out aqueous vapour (in very large quantity), carbonic acid gas, sulphurous acid gas, and sometimes fumes of sulphur.†

But in reply Dr. Daubeny has remarked, that muriatic acid may have ceased to be disengaged, because the volcanic action has become languid in equatorial

* Davy, Phil. Trans. 1828, p. 244.

† Ann. de Chim. et de Phys. tom. lii. p. 181.

America. Sea-water may no longer obtain admission, or the heat may be inadequate to cause the union of the alkali of the sea salt with the earths present, or, if generated, it may be prevented from rising to the crater by combining with calcareous rocks through which it has to pass.*

M. Gay Lussac, while he avows his opinion that the decomposition of water contributes largely to volcanic action, calls attention, nevertheless, to the fact, that hydrogen has not been detected in a separate form among the gaseous products of volcanos; nor can it, he says, be present; for, in that case, it would be inflamed in the air by the red-hot stones thrown out during an eruption. Dr. Davy, also, in his account of Graham Island, says, "I watched when the lightning was most vivid, and the eruption of the greatest degree of violence, to see if there was any inflammation occasioned by this natural electric spark — any indication of the presence of inflammable gas; but in vain." †

May not the hydrogen, Gay Lussac inquires, be combined with chlorine, and produce muriatic acid? for this gas has been observed to be evolved from Vesuvius — and the chlorine may have been derived from sea salt; which was, in fact, extracted by simple washing from the Vesuvian lava of 1822, in the proportion of nine per cent.‡ But it was answered, that Sir H. Davy's experiments had shown, that hydrogen is not combustible when mixed with muriatic acid gas; so that if muriatic gas was evolved in large quantities, the hydrogen might be present without

* Daubeny, Jam. Ed. New Phil. Journ. No. lii. p. 298.

† Phil. Trans., 1832, p. 240.

‡ Ann. de Chim. et de Phys. tom. xxii.

inflammation.* M. Abich, however, assures us, "that although it be true that vapour illuminated by incandescent lava has often been mistaken for flame," yet he clearly detected in the eruption of Vesuvius in 1834 the flame of hydrogen.†

M. Gay Lussac, in the memoir just alluded to, expresses doubt as to the presence of sulphurous acid; but the abundant disengagement of this gas during eruptions is now ascertained: and thus all difficulty in regard to the general absence of hydrogen in an inflammable state is removed; for, as Dr. Daubeny suggests, the hydrogen of decomposed water may unite with sulphur to form sulphuretted hydrogen gas, and this gas will then be mingled with the sulphurous acid as it rises to the crater. It is shown by experiment, that these gasses mutually decompose each other when mixed where steam is present; part of the hydrogen of the one immediately uniting with the oxygen of the other to form water, while the excess of sulphurous acid alone escapes into the atmosphere. Sulphur is at the same time precipitated.

This explanation is sufficient, but it may also be observed that the flame of hydrogen would rarely be visible during an eruption; as that gas, when inflamed in a pure state, burns with a very faint blue flame, which even in the night could hardly be perceptible by the side of red hot and incandescent cinders. Its immediate conversion into water when inflamed in the atmosphere, might also account for its not appearing in a separate form.

Dr. Daubeny is of opinion that water containing

* Quart. Journ. of Science, 1823, p. 132. note by editor.

† Phénom. Géol., &c. p. 3.

atmospheric air may descend from the surface of the earth to the volcanic foci, and that the same process of combustion by which water is decomposed may deprive such subterranean air of its oxygen. In this manner he explains the great quantities of nitrogen evolved from volcanic vents, and thermal waters, and the fact that air disengaged from the earth in volcanic regions is either wholly or in part deprived of its oxygen.

Sir H. Davy, in his memoir on the "Phenomena of Volcanos," remarks, that there was every reason to suppose in Vesuvius the existence of a descending current of air; and he imagined that subterranean cavities which threw out large volumes of steam during the eruption, might afterwards, in the quiet state of the volcano, become filled with atmospheric air.* The presence of ammoniacal salts in volcanic emanations, and of ammonia in lava, favours greatly the notion of air as well as water being deoxidated in the interior of the earth.†

It has been alleged by Professor Bischoff that the slight specific gravity of the metals of the alkalies is fatal to Davy's hypothesis, for if the mean density of the earth, as determined by astronomers, surpass that of all kinds of rocks, these metals cannot exist, at least not in great quantities in the interior of the earth.‡ But Dr. Daubeny has shown, that if we take the united specific gravity of potassium, sodium, silicon, iron, and all the materials which, when united with oxygen, con-

* Phil. Trans. 1828.

† Ammonia is composed of hydrogen and nitrogen; or the elements of air without its oxygen. See Daubeny, Encyc. Metrop. Part 40.

‡ Jam. Ed. New Phil. Journ. No. li. p. 31.

stitute ordinary lava, and then compare their weight with lava of equal bulk, the difference is not very material, the specific gravity of the lava only exceeding by about one fourth that of the unoxidized metals. Besides, at great depths the metallic bases of the earths and alkalies may very probably be rendered heavier by pressure.*

To conclude this part of our inquiry, there appears no sound objection to the doctrine, that chemical changes, going on at various depths in the earth, may be the cause of volcanic action, and that the contact of water with the unoxidized metals of the earths and alkalies may give rise to the heat required. The hydrogen, evolved during the process of saturation, may, on coming afterwards in contact with the heated metallic oxides, reduce them again to metals; and this circle of action may be one of the principal means by which internal heat, and the stability of the volcanic energy, are preserved.

Cause of volcanic eruptions.—The most probable causes of a volcanic outburst at the surface have been in a great degree anticipated in the preceding speculations on the liquefaction of rocks and the generation of gases. When a minute hole is bored in a tube filled with gas condensed into a liquid, the whole becomes instantly aëriform, or, as some writers have expressed it, "flashes into vapour," and often bursts the tube. Such an experiment may represent the mode in which gaseous matter may rush through a rent in the rocks, and continue to escape for days or weeks through a small orifice, with an explosive power sufficient to

* See Daubeny's Reply to Bischoff, Jam. Ed. New Phil. Journ. No. lii. p. 291.; and note in No. liii. p. 158.

reduce every substance which opposes its passage into small fragments or even dust. Lava may be propelled upwards at the same time, and ejected in the form of scoriæ. In some places, where the fluid lava lies at the bottom of a deep fissure, communicating, on the one hand, with the surface, and on the other with a cavern in which a considerable body of vapour has been formed, there may be an efflux of lava, followed by the escape of gas. Eruptions often commence and close with the discharge of vapour: and, when this is the case, the next outburst may be expected to take place by the same vent, for the concluding evolution of elastic fluids will keep open the duct, and leave it unobstructed.

The breaking out of lava from the side or base of a lofty cone, rather than from the summit, may be attributed to the hydrostatic pressure to which the flanks of the mountain are exposed, when the column of lava has risen to a great height. If, before it has reached the top, there should happen to be a stoppage of the main duct, the upward pressure of the ascending column of gas and lava may be sufficient to burst a lateral opening.

Geysers of Iceland. — As aqueous vapour constitutes the most abundant of the aëriform products of volcanos in eruption, it may be well to consider attentively a case in which steam is exclusively the moving power — that of the Geysers of Iceland. These intermittent hot springs occur in a district situated in the south-western division of Iceland, where nearly one hundred of them are said to break out within a circle of two miles. They rise through a thick current of lava, which may perhaps have flowed from Mount Hecla, the summit of that volcano being seen from the spot at the distance of more than thirty miles.

In this district, the rushing of water is sometimes heard in chasms beneath the surface; for here, as on Etna, rivers flow in subterranean channels through the porous and cavernous lavas. It has more than once happened, after earthquakes, that some of the boiling fountains have increased or diminished in violence and volume, or entirely ceased, or that new ones have made their appearance — changes which may be explained by the opening of new rents and the closing of preëxisting fissures. It has often been reported that the powers of the Geysers are, upon the whole, on the decline; but the description given by Mr. Barrow, jun. of the eruptions in 1834, agrees very closely with that of Sir J. Banks, written more than 60 years before.*

Few of the Geysers play longer than five or six minutes at a time, and the intervals between their eruptions are for the most part very irregular. The great Geyser rises out of a spacious basin at the summit of a circular mound composed of siliceous incrustations deposited from the spray of its waters. The diameter of this basin, in one direction, is fifty-six feet, and forty-six in another. (See fig. 72.)

In the centre is a pipe seventy-eight feet in perpendicular depth, and from eight to ten feet in diameter, but gradually widening, as it rises into the basin. The inside of the basin is whitish, consisting of a siliceous crust, and perfectly smooth, as are likewisetw o small channels on the sides of the mound, down which the water escapes when the bowl is filled to the margin. The circular basin is sometimes empty,. as represented in the following sketch; but is usually filled with beauti-

* See Barrow's visit to Iceland, ch. vi. 1834.

Fig. 72.

*View of the Crater of the great Geyser in Iceland.**

fully transparent water in a state of ebullition. During the rise of the boiling water in the pipe, especially when the ebullition is most violent, and when the water is thrown up in jets, subterranean noises are heard, like the distant firing of cannon, and the earth is slightly shaken. The sound then increases and the motion becomes more violent, till at length a column of water is thrown up, with loud explosions, to the height of one or two hundred feet. After playing for a time, like an artificial fountain, and giving off great clouds of vapour, the pipe or tube is emptied; and a column of steam rushing up with amazing force and a thundering noise, terminates the eruption.

If stones are thrown into the crater, they are instantly ejected; and such is the explosive force, that

* Reduced from a sketch given by W. J. Hooker, Esq., in his Tour in Iceland, vol. i. p. 149.

very hard rocks are sometimes shivered by it into small pieces. Henderson found that by throwing a great quantity of large stones into the pipe of Strockr, one of the Geysers, he could bring on an eruption in a few minutes.* The fragments of stone, as well as the boiling water, were thrown in that case to a much greater height than usual. After the water had been ejected, a column of steam continued to rush up with a deafening roar for nearly an hour; but the Geyser, as if exhausted by this effort, did not send out a fresh eruption when its usual interval of rest had elapsed.

Among the different theories proposed to account for these phenomena, I shall first mention one suggested by Sir J. Herschel. An imitation of these jets, he says, may be produced on a small scale, by heating red-hot the stem of a tobacco pipe, filling the bowl with water, and so inclining the pipe as to let the water run through the stem. Its escape, instead of taking place in a continued stream, is then performed by a succession of violent explosions, at first of steam alone, then of water mixed with steam; and, as the pipe cools, almost wholly of water. At every such paroxysmal escape of the water, a portion is driven back, accompanied with steam, into the bowl. The intervals between the explosions depend on the heat, length, and inclination of the pipe; their continuance, on its thickness and conducting power.† The application of this experiment to the Geysers merely requires that a subterranean stream, flowing through the pores and crevices of lava, should suddenly reach a fissure, in which the rock is red-hot, or nearly so. Steam would immediately be formed, which, rushing

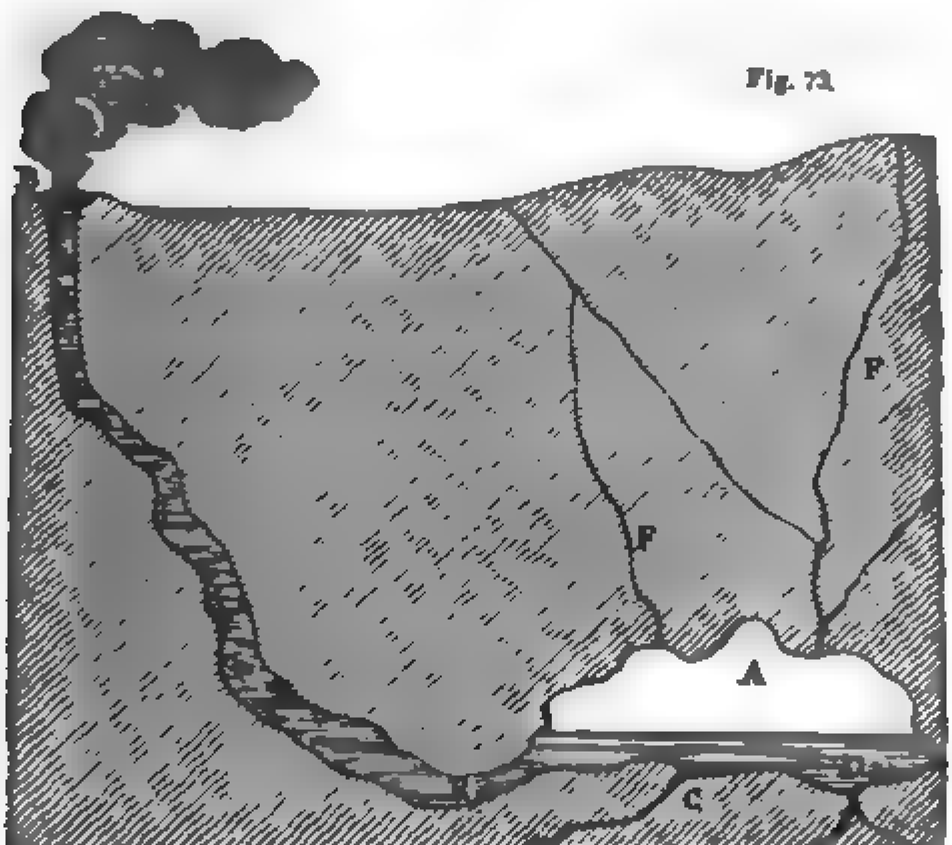
* Journal of a Residence in Iceland, p. 74.

† MS. read to Geol. Soc. of London, Feb. 29. 1832.

the fissure, might force up water along with it to e surface, while, at the same time, part of the steam night drive back the water of the supply for a certain listance towards its source. And when, after the space of some minutes, the steam was all condensed, the water would return, and a repetition of the phenomena take place.

There is, however, another mode of explaining the action of the Geyser, perhaps more probable than that above described. Suppose water percolating from the surface of the earth to penetrate into the subterranean cavity A D (Fig. 73) by the fissures F F, while, at the

Fig. 73.



Supposed reservoir and pipe of a Geyser in Iceland.*

same time steam, at an extremely high temperature,

* From Sir George Mackenzie's Iceland.

such as is commonly given out from the rents of lava currents during congelation, emanates from the fissures C. A portion of the steam is at first condensed into water, while the temperature of the water is raised by the latent heat thus evolved, till, at last, the lower part of the cavity is filled with boiling water and the upper with steam under high pressure. The expansive force of the steam becomes, at length, so great, that the water is forced up the fissure or pipe E B, and runs over the rim of the basin. When the pressure is thus diminished, the steam in the upper part of the cavity A expands, until all the water D is driven into the pipe; and when this happens, the steam, being the lighter of the two fluids, rushes up through the water with great velocity. If the pipe be choked up artificially, even for a few minutes, a great increase of heat must take place; for it is prevented from escaping in a latent form in steam; so that the water is made to boil more violently, and this brings on an eruption.

If we suppose that large subterranean cavities exist at the depth of some miles below the surface of the earth, in which melted lava accumulates, and that water penetrates into these, the steam thus generated may press upon lava and force it up the duct of a volcano, in the same manner as a column of water is driven up the pipe of a Geyser.

Causes of earthquakes — wave-like motion.— I shall now proceed to examine the manner in which the heat of the interior may give rise to earthquakes. One of the most common phenomena attending subterranean movements, is the undulatory motion of the ground. And this, says Michell, will seem less extraordinary, if we call to mind the extreme elasticity of the earth and the compressibility of even the most solid mate-

rials. Large districts, he suggests, may rest on fluid lava; and, when this is disturbed, its motions may be propagated through the incumbent rocks. He also adds the following ingenious speculation: — "As a small quantity of vapour almost instantly generated at some considerable depth below the surface of the earth will produce a vibratory motion, so a very large quantity (whether it be generated almost instantly, or in any small portion of time) will produce a wave-like motion. The manner in which this wave-like motion will be propagated may, in some measure, be represented by the following experiment: — Suppose a large cloth, or carpet (spread upon a floor), to be raised at one edge, and then suddenly brought down again to the floor; the air under it, being by this means propelled, will pass along, till it escapes at the opposite side, raising the cloth in a wave all the way as it goes. In like manner, a large quantity of vapour may be conceived to raise the earth in a wave, as it passes along between the strata, which it may easily separate in a horizontal direction, there being little or no cohesion between one stratum and another. The part of the earth that is first raised, being bent from its natural form, will endeavour to restore itself by its elasticity; and the parts next to it being to have their weight supported by the vapour, which will insinuate itself under them, will be raised in their turn, till it either finds some vent, or is again condensed by the cold into water, and by that means prevented from proceeding any farther." *

To this hypothesis of Michell it has been objected,

* On the Cause and Phenomena of Earthquakes, Phil. Trans., vol. li. sect. 58. 1760.

with some reason, that the wave-like movements of the surface of the land during earthquakes, though violent, are on a very minute scale; as appears from the account of tall trees touching the ground with their tops, and then resuming their erect position, the sea-sickness experienced by spectators, and other phenomena, clearly indicating that the radius of each superficial curvature is very small. It has been suggested, that a vibratory jar may be produced at a considerable depth by the sudden fracture of the solid crust, and that the vibrations may be propagated upwards through a mass of rock several thousand feet, or several miles, thick. The first vibration which reaches the surface will lift up the soil, and then allow it to sink again, immediately after which another which may have radiated from the same deep-seated point may arrive at a contiguous spot on the surface, and cause a similar rise and fall, and so others in succession giving rise to a progressive motion of the ground very similar in appearance to a wave of the sea.

The facility with which all the particles of a solid mass can be made to vibrate, may be illustrated, says Gay Lussac, by many familiar examples. If we apply the ear to one end of a long wooden beam, and listen attentively when the other end is struck by a pin's head, we hear the shock distinctly; which shows that every fibre throughout the whole length has been made to vibrate. The rattling of carriages on the pavement shakes the largest edifices; and in the quarries underneath some quarters in Paris, it is found that the movement is communicated through a considerable thickness of rock.*

* Ann. de Ch. et de Ph., tom. xxii. p. 428.

The rending and upheaving of continental masses are operations which are not difficult to explain, when we are once convinced that heat, of sufficient power not only to melt, but to reduce to a gaseous form a great variety of substances, is accumulated in certain parts of the interior. We see that elastic fluids are capable of projecting solid masses to immense heights in the air; and the volcano of Cotopaxi has been known to throw out, to the distance of eight or nine miles, a mass of rock about one hundred cubic yards in volume. When we observe these aëriform fluids rushing out from particular vents for months, or even years, continuously, what power may we not expect them to exert in other places, where they happen to be confined under an enormous weight of rock?

Liquid gases.—The experiments of Faraday and others have shown, within the last twelve years, that many of the gases, including all those which are most copiously disengaged from volcanic vents, as the carbonic, sulphurous, and muriatic acids, may be condensed into liquids by pressure. At temperatures of from 30° to 50° F., the pressure required for this purpose varies from fifteen to fifty atmospheres; and this amount of pressure we may regard as very insignificant in the operations of nature. A column of Vesuvian lava that would reach from the lip of the crater to the level of the sea, must be equal to about three hundred atmospheres; so that, at depths which may be termed moderate in the interior of the crust of the earth, the gases may be condensed into liquids, even at very high temperatures. The method employed to reduce some of these gases to a liquid state is, to confine the materials, from the mutual action of which they are evolved, in tubes hermetically sealed, so that

the accumulated pressure of the vapour, as it rises and expands, may force some part of it to assume the liquid state. A similar process may, and indeed must, frequently take place in subterranean caverns and fissures, or even in the pores and cells of many rocks; by which means, a much greater store of expansive power may be *packed* into a small space than could happen if these vapours had not the property of becoming liquid. For, although the gas occupies much less room in a liquid state, yet it exerts exactly the same pressure upon the sides of the containing cavity as if it remained in the form of vapour.

If a tube, whether of glass or other materials, filled with condensed gas, have its temperature slightly raised, it will often burst; for a slight increment of heat causes the elasticity of the gas to increase in a very high ratio. We have only to suppose certain rocks permeated by these liquid gases (as porous strata are sometimes filled with water), to have their temperature raised some hundred degrees, and we obtain a power capable of lifting superincumbent masses of almost any conceivable thickness: while, if the depth at which the gas is confined be great, there is no reason to suppose that any other appearances would be witnessed by the inhabitants of the surface than vibratory movements and rents, from which no vapour might escape. In making their way through fissures a very few miles only in length, or in forcing a passage through soft yielding strata, the vapours may be cooled and absorbed by water. For water has a strong affinity to several of the gases; and will absorb large quantities, with a very slight increase of volume. In this manner, the heat or the volume of springs may be augmented, and their mineral properties made to vary.

Connexion between the state of the atmosphere and earthquakes.—The inhabitants of Stromboli, who are mostly fishermen, are said to make use of that volcano as a weather-glass, the eruptions being comparatively feeble when the sky is serene, but increasing in turbulence during tempestuous weather, so that in winter the island often seems to shake from its foundations. Mr. Scrope, after calling attention to these and other analogous facts, first started the idea, that the diminished pressure of the atmosphere, the concomitant of stormy weather, may modify the intensity of the volcanic action. He suggests, for example, that where liquid lava communicates with the surface, as in the crater of Stromboli, it may rise or fall in the vent on the same principle as mercury in a barometer; because the ebullition or expansive power of the steam contained in the lava would be checked by every increase, and augmented by every diminution of weight. In like manner, if a bed of liquid lava be confined at an immense depth below the surface, its expansive force may be counteracted partly by the weight of the incumbent rocks, and also in part by atmospheric pressure acting contemporaneously on a vast superficial area. In that case if the upheaving force increase gradually in energy it will at length be restrained by only the slightest degree of superiority in the antagonist or repressive power, and then the equilibrium may be suddenly destroyed by any cause, such as an ascending draught of air, which is capable of depressing the barometer. In this manner we may account for the remarkable coincidence so frequently observed between the state of the weather and subterranean commotions, although it must be admitted that earthquakes and volcanic eruptions re-act in their turn upon the atmosphere, so that

disturbances of the latter are generally the consequences rather than the forerunners of volcanic disturbances.*

Permanent elevation and subsidence.—It is easy to conceive that the shattered rocks may assume an arched form during a convulsion, so that the country above may remain permanently upheaved. In other cases gas may drive before it masses of liquid lava, which may thus be injected into newly opened fissures. The gas having then obtained more room, by the forcing up of the incumbent rocks, may remain at rest; while the lava, congealing in the rents, may afford a solid foundation for the newly raised district.

Experiments have recently been made in America, by Colonel Totten, to ascertain the ratio according to which some of the stones commonly used in architecture expand with given increments of heat.† It was found impossible, in a country where the annual variation of temperature was more than 90° F., to make a coping of stones, five feet in length, in which the joints should fit so tightly as not to admit water between the stone and the cement; the annual contraction and expansion of the stones causing, at the junctions, small crevices, the width of which varied with the nature of the rock. It was ascertained that fine-grained granite expanded with 1° F. at the rate of ·000004825; white crystalline marble ·000005668; and red sandstone ·000009532, or about twice as much as granite.

Now, according to this law of expansion, a mass of sandstone, a mile in thickness, which should have its temperature raised 200° F., would lift a super-

* Scrope on Volcanos, pp. 58—60.

† Silliman's American Journ., vol. xxii. p. 136. The application of these results to the theory of earthquakes, was first suggested to me by Mr. Babbage.

imposed layer of rock to the height of ten feet above its former level. But, suppose a part of the earth's crust, one hundred miles in thickness and equally expansible, to have its temperature raised 600° or 800°, this might produce an elevation of between two and three thousand feet. The cooling of the same mass might afterwards cause the overlying rocks to sink down again and resume their original position. By such agency we might explain the gradual rise of Scandinavia or the subsidence of Greenland, if this last phenomenon should also be established as a fact on further inquiry.

It is also possible that as the clay in Wedgwood's pyrometer contracts, by giving off its water, and then, by incipient vitrification; so, large masses of argillaceous strata in the earth's interior may shrink, when subjected to heat and chemical changes, and allow the incumbent rocks to subside gradually. It may frequently happen that fissures of great extent may be formed in rocks simply by the unequal expansion of a continuous mass, heated in one part, while in another it remains at a comparatively low temperature. The sudden subsidence of land may also be occasioned by subterranean caverns giving way, when gases are condensed, or when they escape through newly-formed crevices. The subtraction, moreover, of matter from certain parts of the interior, by the flowing of lava, and of mineral springs, must, in the course of ages, cause vacuities below, so that the undermined surface may at length fall in.

The balance of dry land, how preserved.—In the present state of our knowledge, we cannot pretend to estimate the average number of earthquakes which may happen in the course of a single year. As the

area of the ocean is nearly three times that of the land, it is probable that about three sub-marine earthquakes may occur for one exclusively continental; and when we consider the great frequency of slight movements in certain districts, we can hardly suppose that a day ever passes without one or more shocks being experienced in some part of the globe. We have also seen that in Sweden, and other countries, changes in the relative level of sea and land may take place without commotion, and these perhaps produce the most important geographical and geological changes; for the position of land may be altered to a greater amount by an elevation or depression of one inch over a vast area, than by the sinking of a more limited tract, such as the forest of Aripao, to the depth of many fathoms at once.*

It must be evident, from the historical details above given, that the force of subterranean movement, whether intermittent or continuous, whether with or without disturbance, does not operate at random, but is developed in certain regions only; and although the alterations produced during the time required for the occurrence of a few volcanic eruptions may be inconsiderable, we can hardly doubt that, during the ages necessary for the formation of large volcanic cones, composed of thousands of lava currents, shoals might be converted into lofty mountains, and low lands into deep seas.

In a former chapter, I have stated that aqueous and igneous agents may be regarded as antagonist forces; the aqueous labouring incessantly to reduce the inequalities of the earth's surface to a level, while the igneous are equally active in renewing the unevenness

* See p. 322.

of the surface.* By some geologists it has been thought that the levelling power of running water was opposed rather to the *elevating* force of earthquakes than to their action generally. This opinion is, however, untenable; for the sinking down of the bed of the ocean is one of the means by which the gradual submersion of land is prevented. The depth of the sea cannot be increased at any one point without a universal fall of the waters, nor can any partial deposition of sediment occur without the displacement of a quantity of water of equal volume, which will raise the sea, though in an imperceptible degree, even to the antipodes. The preservation, therefore, of the dry land may sometimes be effected by the subsidence of part of the earth's crust (that part, namely, which is covered by the ocean), and in like manner an upheaving movement must often tend to destroy land; for if it render the bed of the sea more shallow, it will displace a certain quantity of water, and thus tend to submerge low tracts.

Astronomers having proved that there has been no change in the diameter of the earth during the last two thousand years, we may assume it as probable, that the dimensions of the planet remain uniform.† If, then, we inquire in what manner the force of earthquakes must be regulated, in order to restore perpetually the inequalities of the surface which the levelling power of water tends to efface, it will be found, that the amount of depression must exceed that of elevation. It would be otherwise if the action of volcanos and mineral springs were suspended; for then the forcing outwards of the earth's envelope ought to be no more than equal to its sinking in.

* Book ii. chap. i. † Book i. chap. viii.

To understand this proposition more clearly, it must be borne in mind, that the deposits of rivers and currents probably add as much to the height of lands which are rising, as they take from those which have risen. Suppose a large river to bring down sediment to a part of the ocean two thousand feet deep, and that the depth of this part is gradually reduced by the accumulation of sediment till only a shoal remains, covered by water at high tides; if now an upheaving force should uplift this shoal to the height of 2000 feet, the result would be a mountain 2000 feet high. But had the movement raised the same part of the bottom of the sea before the sediment of the river had filled it up; then, instead of changing a shoal into a mountain 2000 feet high, it would only have converted a deep sea into a shoal.

It appears, then, that the operations of the earthquake are often such as to cause the levelling power of water to counteract itself; and, although the idea may appear paradoxical, we may be sure, wherever we find hills and mountains composed of stratified deposits, that such inequalities of the surface would have had no existence if water, at some former period, had not been labouring to reduce the earth's surface to one level.

But, besides the transfer of matter by running water from the continents to the ocean, there is a constant transportation from below upwards, by mineral springs and volcanic vents. As mountain masses are, in the course of ages, created by the pouring forth of successive streams of lava, so stratified rocks, of great extent, originate from the deposition of carbonate of lime, and other mineral ingredients, with which springs are impregnated. The surface of the land, and por-

tions of the bottom of the sea, being thus raised, the external accessions due to these operations would cause the dimensions of the planet to enlarge continually, if the amount of depression of the earth's crust were no more than equal to the elevation. In order, therefore, that the mean diameter of the earth should remain uniform, and the unevenness of the surface be preserved, it is necessary that the amount of subsidence should be in excess. And such a predominance of depression is far from improbable, on mechanical principles, since every upheaving movement must be expected either to produce caverns in the mass below, or to cause some diminution of its density Vacuities must, also, arise from the subtraction of the matter poured out from volcanos and mineral springs, or from the contraction of argillaceous masses by subterranean heat; and the foundations having been thus weakened, the earth's crust, shaken and rent by reiterated convulsions, must, in the course of time, fall in.

If we embrace these views, important geological consequences will follow; since, if there be, upon the whole, more subsidence than elevation, the average depth to which former surfaces have sunk beneath their original level must exceed the height which ancient marine strata have attained above the sea. If, for example, marine strata, about the age of our chalk and green-sand, have been lifted up in Europe to an extreme height of more than eleven thousand feet, and a mean elevation of some hundreds, we may conclude that certain parts of the surface, which existed when those strata were deposited, have sunk to an extreme depth of *more than* eleven thousand feet below their

original level, and to a mean depth of *more than* a few hundreds.

In regard to faults, also, we must infer, according to the hypothesis now proposed, that a greater number have arisen from the sinking down than from the elevation of rocks.

To conclude: it seems to be rendered probable, by the views above explained, that the constant repair of the land, and the subserviency of our planet to the support of terrestrial as well as aquatic species, are secured by the elevating and depressing power of causes acting in the interior of the earth; which, although so often the source of death and terror to the inhabitants of the globe — visiting in succession every zone, and filling the earth with monuments of ruin and disorder — are nevertheless the agents of a conservative principle above all others essential to the stability of the system.

END OF THE SECOND VOLUME.